Aalto University

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Improving Installed Base Information Utilization in a Preventive Maintenance Field Service Process

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Technology

Espoo, November 6, 2012

Supervisor Professor Jan Holmström
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AALTO UNIVERSITY SCHOOLS OF TECHNOLOGY PO Box 11000, FI-00076 AALTO http://www.aalto.fi	ABSTRACT OF THE MASTER'S THESIS

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Title: Improving Installed Base Information Utilization in a Preventive Maintenance Field Service Process

School: School of Engineering

Department: Department of Engineering Design and Production

Professorship: Industrial Management | Code: TU-22

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Abstract:

This thesis explores how the flow of information should be improved in a preventive maintenance field service process. Its motivation stems from the growing pressure on capital goods manufacturers to servitize, and the difficulties experienced when servitizing. Due to the heterogeneity of customer inputs, which is inherent to services, efficient operations can only be achieved through improving the flow of information. Realized as a prescriptive single case-study, the thesis provides a tool for analyzing the flow of information, along with a performance measurement method for identifying under- and over-maintenance in the preventive maintenance context.

The primary purpose of the developed tool is to tie information to value in order to facilitate investments in improving the flow of information. The tool was realized through building a literature framework, consisting of five constructs; information, decision, action, outcome and value. The literature framework was applied in the case analysis, where it revealed a set of challenges related to the flow of information. The most significant improvement potential was found in the way the preventive maintenance plans were created, as there were no subsequent attempts to evaluate the performance of these plans. The analysis resulted in eight design propositions, of which the first was intended to reach the untapped potential mentioned above, through introducing a learning mechanism to the process.

The first design proposition was further analyzed in an attempt to quantify the effect of its implementation. The proposed learning mechanism consists of two measures which indicate whether the equipment specific maintenance plan in question should be adjusted. The two measures were tested using case company service data, which confirmed that the case company is on average over-maintaining its service base. Additionally the analysis indicated room for improvement where frequently failing equipment was subjected to less maintenance than equipment with no failures during the studied timespan.

Aside of the case specific recommendations, the thesis contributes to several fields of research. In servitization research there has been a call for tools to manage the transition from pure manufacturer to servitized manufacturer, to which the developed tool is a direct answer. The quantification of over-maintenance is also a significant advancement in the field of preventive maintenance. Further contributions were made to the fields of installed base information and operational decision-making.

Date: 6.11.2012	Language: English	Number of pages: 92 + 18

Keywords: servitization, preventive maintenance, installed base information, process improvement, operational decision making, over-maintenance, case study

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DIPLOMITYÖN TIIVISTELMÄ

Tekijä: Mikael Öhman

Työn nimi: Asennetun laitekantatiedon hyödyntäminen ennakoivan huollon kenttäpalveluprosessissa

Korkeakoulu: Insinööritieteiden korkeakoulu

Laitos: Koneenrakennustekniikan laitos

Professuuri: Teollisuustalous | Koodi: TU-22

Työn valvoja: Professori Jan Holmström

Työn ohjaaja: Diplomi-insinööri Max Finne

Tiivistelmä:

Tämän diplomityön tavoitteena on analysoida ja kehittää kohdeyrityksen ennakoivan huollon kenttäpalvelu-prosessin asennetun laitekantatiedon hyödyntämistä. Tavoite kumpuaa investointihyödykkeitä valmistavien yritysten palvelullistumisesta, joka lisää palveluliiketoiminnan osuutta koko liiketoiminnasta. Palvelujen toiminnanohjaus eroaa tuotannon toiminnanohjauksesta pääasiallisesti siten, että tehokkuuden kannalta olennaista asiakassyötteen vaihtelua ei voida poistaa, vaan sitä on hallittava lisäämällä tiedonkulkua. Tässä case-tutkimuksessa kehiteltiin tiedonkulun analysointia helpottava työkalu, sekä ennakoivan huollon käyttöön tarkoitettu yli- ja alihuoltamisen mittaristo.

Tiedonkulun analysointiin tarkoitettu työkalu kehitettiin tiedonkulkua parantavien investointien tueksi. Työkalu toteutettiin kirjallisuuteen perustuvana viitekehyksenä, jossa on viisi keskeistä käsitettä; tieto, päätöksenteko, toiminta, seuraukset ja arvo. Työkalun avulla kohdeyrityksen ennakoivan huollon prosessi analysoitiin, jonka seurauksena tunnistettiin joukko tiedonkulkuun liittyviä haasteita. Suurin parannuspotentiaali löytyi tavasta jolla ennakoivan huollon suunnitelmat luotiin, jossa haaste perustui siihen että luodun suunnitelman suorituskykyä ei luomisen jälkeen arvioitu. Analyysin perusteella kehiteltiin kahdeksan parannusehdotusta, joista ensimmäinen vastasi yllä mainittuun haasteeseen ehdottamalla prosessiin oppimisominaisuutta.

Ensimmäisen parannusehdotuksen perusteella tehtiin jatko-analyysi, jonka tavoitteena oli parannusehdotuksen toteuttamisen vaikutusten tarkempi arviointi. Oppimisominaisuus pohjautuu kahteen mittariin, joiden perusteella ennakoivan huollon suunnitelmaa säädetään. Mittareita kokeiltiin kohdeyrityksen toimittamien huollon tietokantaotteiden avulla, joiden perusteella pystyttiin toteamaan että kohdeyritys keskimääräisesti ylihuoltaa huoltokantaansa. Lisäksi havaittiin että jatkuvasti vikaantuvia laitteita huollettiin joissain tapauksissa vähemmän kuin nollavikaisia.

Kohdeyrityskohtaisten suositusten ohella diplomityö osallistuu tieteelliseen keskusteluun usealla tieteenalalla. Palvelullistumiskeskustelussa on peräänkuulutettu käytännön työkaluja joiden avulla yritykset voisivat edesauttaa palveluympäristöön sopeutumista, johon kehitetty työkalu on suora vastaus. Ali- ja ylihuollon mittaaminen taas on huoltotoiminnan tutkimuksessa merkittävä edistysaskel. Diplomityö edistää myös ymmärrystä asennetun laitekantatiedon ja operationaalisen päätöksenteon tutkimusalueilla.

Päivämäärä: 6.11.2012 | Kieli: Englanti | Sivumäärä: 92 + 18

Avainsanat: palvelullistuminen, ennakoiva huolto, asennettu laitekantatieto, prosessikehitys, operationaalinen päätöksenteko, ylihuoltaminen, case-tutkimus

Preface

The journey began, driven by curiosity and excitement. It continued through time, crossing valleys and climbing peaks. At times the path was shadowed by doubt, regret, anxiety and even despair. At times it was illuminated by joy, inspiration, discovery and even enlightenment. Now, when the end has been reached, it is not the destination which puts the smile on my face, but the distance traveled.

This journey was made easy by the ones accompanying me on it. I would hereby like to thank my supervisor, Professor Jan Holmström, for the encouragement, constructive criticism and the occasional implicit friendly reminder that "it's just a thesis". Further, I would like to thank my instructor, Max Finne, for his active participation during the course of the work, attending several meetings with CaseCo, engaging in deep theoretical discussions with little or no warning, and offering almost instant, elaborate constructive feedback on the work done. I would also like to thank the Solution Manager and Data Analysis Specialist at CaseCo; your great patience in the early stages of the study, combined with your availability, responsiveness and flexibility, added up to what I believe is the best imaginable environment for an external thesis worker.

Finally, I would like to thank my wife for supporting me throughout the journey. Her love, kindness and compassion lit up the way where there was darkness, as did the smile of my son Robin. While few things are certain, and even fewer truly important, I know that you two are the center of my universe.

Mikael Öhman
Espoo, December 4, 2012

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Abbreviations and definitions

Call-out	A term used at CaseCo for time-critical corrective maintenance activities, initiated by customer service requests.
CaseCo	Pseudonym for the case company.
Decision logic	A mechanism which converts information into action.
Delivered base	A sub-group of the installed base consisting of the equipment individuals delivered by the focal OEM.
Event data	Installed base information that relates to incidents involving the items and locations as well as describes interventions performed. (Ala-Risku 2009)
Granularity	A measure for the richness of detail in the way something is described.
IBI	Installed Base Information – See below.
Installed base	A set of equipment individuals currently in use. (Ala-Risku 2009)
Installed Base Information	Refers to information on product individuals within the company's delivered- and service bases which are commissioned: their location, owner, user, application, operating environment, status, and service history. (Ala-Risku 2009)
Item data	Installed base information that relates to the installed items – their properties and their condition. (Ala-Risku 2009)
Location data	Installed base information that relates to the position in the customer process that an item can occupy. (Ala-Risku 2009)
Main component	An equipment sub-assembly, with unique function, structure and maintenance requirements, differentiating it from other sub-assemblies.
OEM	Original Equipment Manufacturer – The company by whom the equipment has been manufactured and/or assembled. The abbreviation is also commonly used with spare- and replacement parts manufactured and/or assembled by the same company to manufacture the equipment.
PM	Preventive Maintenance – See below.
PMAS	Preventive Maintenance Allocation System – The CaseCo IT-based system for creating individualized maintenance plans for equipment.
Preventive maintenance	A function which tends to equipment availability and longevity through postponing wear-out failures and detecting impending failures.
Service base	A sub-group of the installed base consisting of the equipment individuals currently under service contract with the focal service provider.

1 Introduction

A constantly changing business environment forces companies to continuously adjust their strategies. Sometimes, changes in the business environment are caused by the businesses themselves, driven by a continuous pursuit of competitive advantage. Alternatively, the pressure to change is exerted by the environment on the businesses and those who choose not to follow will do so at their own peril. Regardless of what ignites the strategic change, the more radical the change is compared to the company's current operations, the more challenges can be expected when implementing.

Today's capital goods manufacturers are living in what could be characterized as a decisive shift in the way they operate and define themselves. The business environment faced by these companies has become harsh due to increased capital supply- and customer demand-related risks, caused by higher mobility of investments, stagnating demand in the western economies and greater macro-economic fluctuations. While globalization has partly contained the problem of stagnating demand with the rise of the eastern tigers, the consequent increasing economic interdependence results in global projection of previously relatively contained national or regional macro-economic fluctuations.

The capital goods manufacturers are typically part of a horizontal supply-chain, ultimately serving a customer who is an upstream manufacturer or service provider in a vertical supply-chain[1], whose ultimate customer is the consumer. This setup implies that, as the macro-economic demand fluctuations are amplified upstream in the vertical supply-chain, where they are directly impacting the demand imposed on the horizontal supply-chain, the short-term demand for the capital goods manufacturer will be highly unstable.

As a result of this, the risks involved with operating on pure transactional basis is one of the reasons why many capital goods manufacturers choose to pursue a relationship-based customer interaction (Oliva & Kallenberg 2003). In practice this has translated to many capital goods manufacturers offering services in connection to their products (e.g. maintenance, operator training and leasing to name a few), resulting in more stable revenue-streams and improved profitability (Wise & Baumgartner 1999).

The transition also typically involves moving from offering product-oriented services towards offering end-user's process-oriented services (Oliva & Kallenberg 2003). This, in combination with the aforementioned transition, has been motivated by both strategic (e.g. competitive opportunity and advantage) and marketing drivers (e.g. customer relationships and product differentiation) (Baines et al. 2009). Both of these transitions however, have proved to be far from simple and easy to implement.

In academia this transition phenomenon has been labeled servitization, and has received increasing attention from scholars since the turn of the century. The term servitization was originally coined by Vandermerwe & Rada (1988), and has since been defined in many different ways. The definitions offered to date have several different emphases, but they all

[1] For concise reading on vertical and horizontal supply-chains, see Beckman & Rosenfield (2008, chap.2)

involve moving towards a greater relative importance of services on the product service continuum (Figure 1, below).

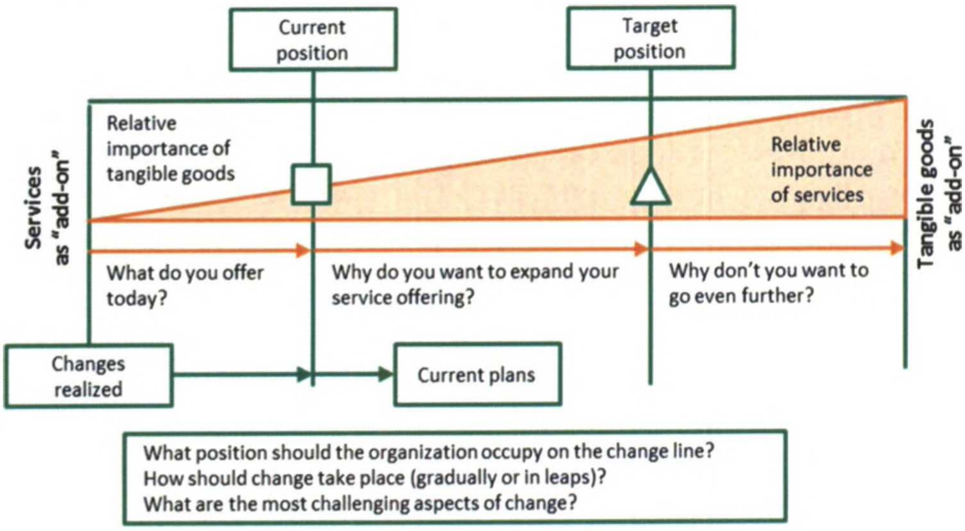

Figure 1 - The product service continuum (applied from Oliva & Kallenberg 2003)

The difficulties related to servitizing have been acknowledged from the very beginning (cf. Vandermerwe & Rada 1988), and Baines et.al. (2009) compartmentalize the challenging areas into service design, organizational strategy and organizational transformation. The root cause for many of the identified challenges can be traced back to the fundamental differences between services and products, and moving from a product- to a customer-centric view (cf. Levitt 1960) of the world. Further, failure is likely when attempting to manage service operations through utilizing manufacturing operations management tools, knowledge and competences (Cohen et al. 2006).

Traditional manufacturing operations management emphasizes building cost efficient, complex and rigid structures, in closed systems within well-defined boundaries. Today's competitive pressures, including the pressure to servitize, requires moving into a constant state of change (Preiss 2005). This in turn implies dealing with systems that are inherently open and borders which are constantly changing and hard to define. In short, the increasing clock speed of the world is not only driving manufacturers toward services, but also towards more service-compatible operations management. The real question is thus not *if* a manufacturer wants to move towards services, but rather *how* it will move towards services.

1.1 Background for the study

Motivated by the challenges companies are facing when servitizing, this thesis was written in the context provided by the Future Industrial Services (FutIS) program. FutIS is a five year strategic research program, motivated by the increasing importance of services in all industries. Initiated by the finish technology agency (TEKES), the vision of the program was defined as follows: "In 2015, Finland is leading country in service business leadership and management. This has been turned into the success of the Finnish industry and their customers" (Stenwall et al. 2010, p.13). The program participants represent a wide range of Finnish firms, research teams and a number of selected international institutes.

In pursuing the vision, the program was divided into three work packages, aimed at addressing service and servitization challenges on levels ranging from strategic to operational. Work package 1 (WP1) addresses the service business mindset while work package 2 (WP2) addresses integrated service development. Work package 3 (WP3), in which this thesis was written, focuses on efficient service operations. The high level objectives of the thesis are thus guided by the purpose of WP3 (Stenwall et al. 2010, p.7):

- To expand understanding on how to design and optimize service operations systems based on information about installed base and customers over equipment life cycle within global service operations systems, with efficient future service operations in mind.
- To develop and evaluate effective, efficient and sustainable information enabled logistics system designs for global service operations.
- Scoping: the work package concentrates on workforce and spare parts service supply chain processes, with efficient future service operations in mind.

After program initiation, the scoping of WP3 quickly changed direction towards installed base information management and showing the value of installed base information. This was due to the finding that involved companies were not struggling as much with the question of *how* to use installed base information, but rather *whether* to use it (Westwood 2011). The infancy of both the concept of installed base information and its application in service operations was in a state reminding of the chicken-and-the-egg dilemma, where the companies could see some potential, but the business cases were challenging to build.

Against this background there was a perceived and clear need of being able to analyze and quantify the value created by the installed base information, in order to secure investments in collection, management and utilization of the information. Despite some success in quantifying the value in specific contexts, where ad-hoc approaches have tied together single elements of information with single elements of value through causal chains, I felt compelled to explore to what extent the relationship between information and value could be determined through a structured and non-context specific approach.

The initial approach for the thesis was to pursue a broad service operations systems perspective (see Figure 2, page 4), attempting to capture high level dynamics in the after sales market through exploring occurrence, structure and un-tapped potential of different provider-customer constellations (cf. Holmström et al. 2010). The plan was to capture the customer's perception of value through demand-chain mapping and to investigate the service delivery processes from the perspective of matching information demand with utilization while assuming full information availability.

When the idea was exposed to company representatives within WP3[2], it soon became clear that there was a lack of interest in pursuing a holistic approach, especially if many companies were to be included in the study. The primary reason was that the subject was perceived extremely broad for a master's thesis, even if it would have been executed within a single case company context.

[2] A total of six servitized large Finnish capital goods manufacturers

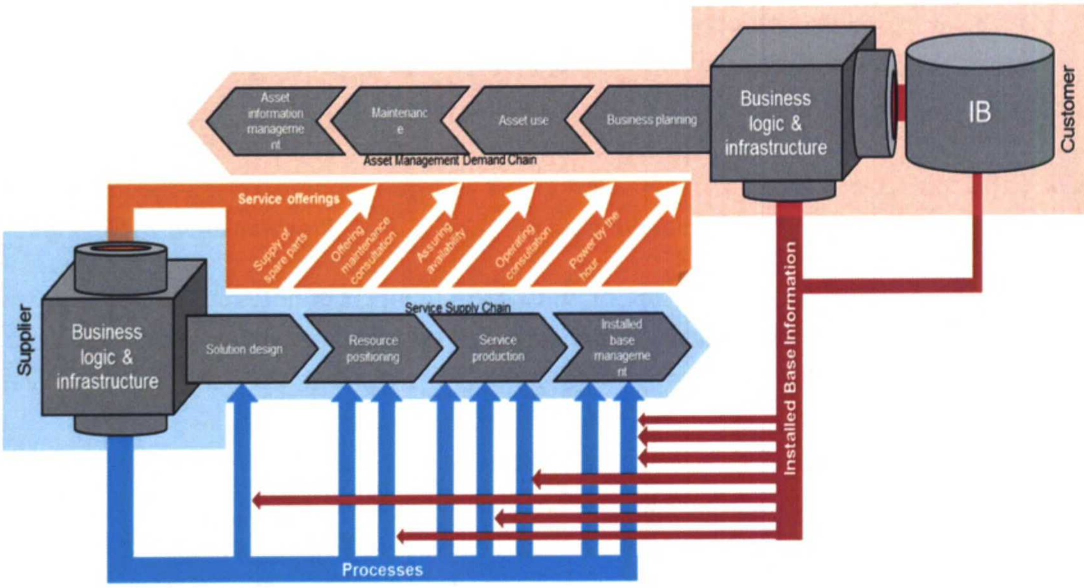

Figure 2 – The service operations system, an attempt to capture the holistic picture

Another aspect of the initial pitching round was to map the interest of the consortium companies with respect to the holistic picture (Figure 2, above). This was done through querying the companies where they saw foci to be attained. Interestingly, no two companies had perfectly aligned interests, which might be perceived as reflecting differences in the maturity of service operations execution and development.

1.2 Case and context selection

Due to lack of interest[3] in a top level holistic approach, company suggestions for foci were evaluated in order to determine where the business and academic objectives were best aligned. Displayed understanding of the initial problem formulation, combined with a feeling of material availability for case research (cf. Yin 1994) the author, in accord with the thesis instructor and supervisor, concluded on pursuing further co-operation with CaseCo (a pseudonym that will be used throughout the thesis to conceal the actual identity of the case company).

CaseCo had expressed particular interest in studying installed base information utilization in their preventive maintenance processes, which served as a good foci suggestion. The appeal of the preventive maintenance context arises from its established position in manufacturing research which can be juxtaposed with its relatively unexplored position in field services. This constitutes a situation where new theory can be built through case research, potentially benefiting both service and manufacturing areas of research (Eisenhardt 1989).

CaseCo was mainly interested in how installed base information could be utilized to create internal value, or reduce waste, resulting in productivity and efficiency improvement. However, access to the customer interface was promised in order to maintain a holistic approach within the chosen foci. Expressed in the form of deliverables, CaseCo was promised a solution for:

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[3] Or rather, skepticism of feasibility

- Describing the ideal installed base information enabled preventive maintenance process
- Benchmarking current practices and identifying opportunities for process redesign
- Supporting installed base information-related investment-decisions

In the next section I will present the research set up and methodology in the way they were designed to facilitate the background and context provided by the FutIS-program. Further the single case study method employed, will be elaborated in order to convey an accurate picture of the rigor of the conducted research.

2 Research setup and methodology

Based on initial analysis of the research background and the selected case context, a research plan was constructed to facilitate and guide the execution of the thesis. However, as could be expected, some scope adjustments were done along the way as knowledge and understanding of the case in its context increased (Yin 1994). In this iterative process, the ratio of resource input and expected added value was a guiding principle for when to adjust scope, however, a clear limitation was imposed by the total resource usage expected for a Master's thesis.

In this section I will begin with presenting the research objectives, research question and other guiding parameters of the work. Then I will provide a closer look into the applied method, where I will argue that considering the circumstances, the single-case study was the dominant research design. After this I will present how the data was collected and discuss the implications on the reliability of the findings, followed by a description of how the study was executed in practice. I will then round up by present the structure of the study from objectives to deliverables and how it is presented in this Master's thesis.

Motivated by both academic and business interests with slightly different perspectives, the objective of this thesis was formulated together with the approach in a way which facilitated both interests. The resource constraint imposed by the master's thesis mentioned above, translated to a tight focus on the preventive maintenance process. In practice this meant sacrificing the holistic service operations system view in favor of a strictly limited process view, while keeping the chain between information and value intact.

The research questions were formulated based on the objective and scope, taking into account the deliverables promised to CaseCo. To sum up, the steering mechanisms of the thesis are presented in Table 1:

Table 1 - Thesis fundamentals

Motivation	Arises from the pressure on manufacturers to move towards services, or servitize, in developed economies. The thesis is highly topical due to the pivotal role of installed base information in field service operations combined with the low maturity of installed base information utilization in practice
Thesis objective	**To uncover the value of installed base information**
Approach	**Devising a framework for describing and quantifying the gap between the current and ideal use of installed base information, and applying the framework successfully in the case company context**
Thesis scope	**The scope of the thesis is information processing within preventive maintenance field service from a process design perspective**
Research questions	**RQ1: How is installed base information currently utilized in preventive maintenance field services, both directly and indirectly?**

	RQ2: How does installed base information utilized in a preventive maintenance field service context translate into value? **RQ3: How can the untapped potential of utilizing installed base information in preventive maintenance field services be reached?**
Unit of analysis	**The preventive maintenance process of CaseCo** - **Region of CaseCo operations**

The initial assumption was that installed base information is currently used to a limited extent in preventive maintenance processes. Installed base information is mainly used in situations where the benefits are easily accessible, beneficial for the one acting based on the information and the mechanism of value creation or waste reduction is easy to comprehend. The translation of information to value is in its current use quite simple, but the perception of how the translation happens is restricted to short causal chains and benefits are not perceived in their full width by any stakeholders.

Considering how installed base information utilization could be improved (RQ3), the initial assumption stated that reduction of "over-maintenance" was suspected to be a major source of untapped potential. The hypothesis was relying on the analogy between the current situation with IBI and the situation in the early 90's when binary data was beginning to be readily available, but the processes which utilized the information were stuck in historical tracks.

When considering the applicability of the results, we should remember that the focus of the thesis is tightly around the preventive maintenance process, meaning that adjacent and co-dependent processes (such as spare part supply chain, resource planning etc.), in the service operations system, are considered only superficially. Additionally, the process design perspective implies limited attention to organizational and cultural issues. Further, the single case design of the study, which will be discussed next, implies that some context specific characteristics raise questions on the generalizability of the results.

2.1 Applied method

The aim of qualitative research is to achieve a rich and holistic understanding of the studied phenomenon. This is a recommended research approach especially when the studied phenomenon is new, and there is no established foundation provided by existing theory, which is the case with installed base information. Qualitative research implies a close relationship between the subject and the researcher and an open research strategy, in order to allow adaptation of the research to facilitate emergent findings. (Hirsjärvi et al. 1997)

Reflected against the objective of the study, a qualitative approach seemed not only appropriate, but rather necessary, as there was a lack of deep and holistic understanding, combined with a nonexistent explicit theoretical foundation. A combination of the available resources and the desired depth of understanding, directed the choice of research strategy towards a single case study. Further, the differences between available case companies in terms of service operations maturity and desired focus implies that cross-case conclusions in an undeveloped field of research could be hard to make.

The conducted single-case study can be divided into three distinct phases, each with a unique configuration considering the chosen methodology (see Table 2, below). The first phase of the case study consisted of concurrent[4] data gathering, analysis and identification of justificatory knowledge[5]. Relying mainly on interviews and documentation, a holistic investigation of the CaseCo preventive maintenance process was conducted while attempting to identify the relevant and sufficient theoretical constructs for describing how information is transformed to value. The result of this highly iterative process was the Analysis of the CaseCo preventive maintenance process and a literature framework, elaborated in the Literature review, which formed the consolidated theoretical basis for the case analysis.

In the second phase, a prescriptive stance was taken, where design propositions were co-created in a joint workshop with the CaseCo representatives based on the challenges found in the first phase. In the third phase, the prescriptive investigation was extended, by testing the feasibility of design proposition 1 through quantitative analysis. In the third phase two different regions, where CaseCo is supplying preventive maintenance services, were contrasted against each other, which effectively extended the single-case study from a holistic- to an embedded case-design (Yin 1994).

Table 2 - Methodological characteristics of different phases in the single-case study

Phase (chapter)	I) Analysis of the CaseCo preventive maintenance process (Thesis chapter 5)[6]	II) Identified challenges and how to address those (Thesis chapter 6)	III) Gap analysis of design proposition 1 (Thesis chapter 7)
Function	Describing the current situation and identifying challenges	developing design propositions	Testing one developed design proposition
Case study type based on the research approach	Qualitative	Qualitative	Quantitative
Case study type based on the purpose of research	Descriptive	Prescriptive	Prescriptive
Case study type based on the unit of analysis	Holistic	Holistic	Embedded

The holistic design has a single unit of analysis, while the embedded design has multiple

[4] In line with the recommendations of Eisenhardt (1989)

[5] "The underlying knowledge or theory from the natural or social or design sciences that gives a basis and explanation for the design (kernel theories)" (Gregor & Jones 2007, p.322)

[6] Chapter 4 is also essential considering the function of this phase, however, it is mainly concentrated on background information and describing underlying dynamics

units of analysis. The holistic single-case design can be further divided, based on rationale, into (Yin 1994):

- **Critical case**, where the case represents the critical case in testing a well-formulated theory with the aim of confirming, challenging or extending the theory
- **Extreme or unique case**, where the case represent a rare instance of an interesting phenomenon, which is the object for the study
- **Revelatory case**, where the investigator has an opportunity to observe and analyze a phenomenon previously inaccessible to scientific investigation

The conducted single-case study should thus be considered as an initial revelatory (and unique) case, which is extended into an embedded case design. The case in its context, I argue, is sufficiently different from its well established natural counterpart (preventive maintenance in manufacturing vs. preventive maintenance field services) for the case to be revelatory. Further, studying the transformation of information into value seemed[7] to involve such complex dynamics that it felt safer to assume case uniqueness at the early stages with limited resources.

As mentioned, the cross-region examination of CaseCo provided service database extracts in research phase 3 implies a shift to an embedded single-case design, effectively tying the single-case down to operational details. This, twofold approach is valuable in the sense that the two parts complement each other with respect to each research strategy's weaknesses (Yin 1994):

- A holistic, global approach allows an investigator to avoid examining any specific operational detail
- The holistic design allows the entire single-case study to be conducted at an abstract level, lacking any clear measures or data
- With the holistic design the entire nature of the single-case study may shift during the course of the study[8]
- With the embedded research design a major pitfall occurs when the case study focuses only on the subunit level and fails to return to the larger unit of analysis

In the three phase design, the holistic first phase a simple approach for describing information utilization, while the second phase is about identifying untapped potential uncovered by the approach. As the third phase aims to quantify the untapped potential, it calls for a subsequent return to evaluation of the effectiveness of the approach used in phases one and two, at the same time mitigating the major weakness of the embedded single-case design.

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[7] Based on the ambiguity of concepts, varying interests and focus, and maturity of thought observed among the involved practitioners during the initiation-stage of the research

[8] "Although some people have claimed such flexibility to be the strength of the case study approach, in fact, the largest criticism of case studies is based on this type of shift – in which the original research design is no longer appropriate for the research question being asked (see Yin et al. 1985)."(Yin 1994, p.42)

Respectively, phase three constitutes a deep dive into operational detail, based on hard data, while at the same time anchoring the focus of the study in trying to prove or disprove the initial hypothesis that reduction of "over-maintenance" is a major source of untapped potential. This means that phase three effectively mitigates the three weaknesses of the holistic single-case research strategy, presented above. Further, a significant contribution of phase three is that it makes extensive use of quantitative evidence, which triangulated against the mainly qualitative evidence of phases one and two, has been stated as a recipe for success in industrial management research (Eisenhardt 1989; R. Beach et al. 2001).

Many of the steps Eisenhardt (1989) prescribes for inducting theory from case study research have been taken. I am however inclined to recognize the deficiencies caused by the single-case design and single investigator research execution. Both of these are caused by restrictions on masters' thesis, imposed through regulation of resource usage both in time and manpower. However, this research was also of a prescriptive nature, which means that a design theory could be proposed based on discovered technological rules (cf. Van Aken 2004; Gregor & Jones 2007; Holmström et al. 2009).

2.2 Data sources, sampling and collection

One of the prime criteria for having CaseCo as the case company was the perceived availability of data. Because the object of study is a business process, we will do well in considering process mapping literature when designing data collection. Apart from the obvious need to understand the logic of the process, consisting of triggers, inputs, transformations and outputs, the foundations and implicit mechanisms for the process, such as business objectives, business risks, key controls and measures of success should also be explored (Jacka & Keller 2002). With this in mind, the body of evidence was constructed through utilizing a wide spectrum of sources.

Table 3 - Evidence

Source	Evidence (p/s)[9]	Description
Documentation	CaseCo maintenance process- and roles description (p)	The internal maintenance process descriptions accompanied by role descriptions, provided confidentially by CaseCo, dated April 2009.
	CaseCo service process educational DVD (s)	An educational (/sales) video describing the maintenance processes.
	Service excellence in CaseCo (Auramo et al. 2008) (s)	A case paper on the field service operations of CaseCo prepared at the BIT research center at Helsinki University of Technology in 2008.
	Recent CaseCo annual reports (s)	Publicly available annual reports accessed through the CaseCo website.
	CaseCo service excellence, sales DVD (s)	A customer-oriented DVD provided by CaseCo.
	Various publicly available marketing materials (s)	Customer-oriented material retrieved from the CaseCo website.
Archival Records	Service history extract, Southern Europe (p)	A service record extract from the CaseCo IT-system, ranging over 2 years and 2 months, and 1058 installed equipment individuals (21.5.2012)

[9] An indication of whether the evidence is considered as primary- (p) or secondary (s) data

	Service history extract, Northern Europe (p)	A service record extract from the CaseCo IT-system, ranging over 2 years and 6 months, and 1838 installed equipment individuals (27.6.2012)
Interviews	Maintenance solution manager (p)	A thematic interview revolving around general context characteristics, the role of maintenance and the maintenance process. Going through the maintenance process descriptions together. (1,5 hours, recorded, 16.12.2011)
	Data analysis specialist (p)	A semi-structured interview on how information is currently used in the maintenance process, with a focus on how the preventive maintenance plans are determined. (2 hours, recorded, 13.1.2012)
	Sales manager (+data analysis specialist) (p)	A semi-structured interview on customer characteristics, service offerings and customer value. The sales manager provided the national perspective, while the data analysis specialist contributed with global insights. (1,5 hours, recorded, 10.2.2012)
	Q&A-sessions with CaseCo representatives (s)	Teleconferences with the maintenance solution manager and data analysis specialist (30 min each, notes taken, 12.3.2012 and 19.3.2012)
Direct Observations	Field trip with maintenance technician (p)	A field trip with a maintenance technician on his service route, performing preventive maintenance actions. Discussion themes were prepared; however, the main purpose of the trip was direct observation of maintenance activities. (3,5 hours, notes taken, 16.5.2012)
Participant Observations	Solution workshop (P)	A facilitated workshop, aimed at identifying untapped potential of installed base information utilization with the maintenance solution manager, data analysis specialist and thesis instructor. (3,5 hours, recorded, 22.3.2012)
	Results discussions (p)	Intermediate results presentations and discussions with the maintenance solution manager, data analysis specialist and thesis instructor. (varying between 1,5 and 2,5 hours, notes taken, 27.2.2012, 2.4.2012, 26.6.2012 and 25.9.2012)

Yin (1994) states that evidence for case studies may come from six major sources; documents, archival records, interviews, direct observation, participant-observation, and physical artifacts. Further, "no single source has a complete advantage over all the others. In fact, the various sources are highly complementary, and a good case study will therefore want to use as many sources as possible" (Yin 1994, p.80). Of these six, five[10] were used in the study during its different phases. While the synergetic nature of the phases render specification of evidence source per phase meaningless, it should be said that phase three relied primarily on archival records. In Table 3, above, I have listed the relevant sources (Yin 1994) and evidence for the study.

The service history data samples used in the second part of the research, were selected based on the following criteria (in the order of importance); data quality, sample size and regional legislative differences. As a result, both of the delivered samples represented high data quality, analyzable[11] samples originating from regions with different legislative

[10] Documentation, Archival records, Interviews, Direct observations and Participant observations
[11] Restrictions mainly imposed by computing power, as the total amount of service events analyzed was close to 100000 events

restrictions regarding maintenance service on the type of equipment in focus. As the focus of the quantitative study was in analyzing the effect of preventive maintenance on equipment failure, the differences in legislation were not only acceptable, but desirable.

Based on the spectrum of evidence (presented in Table 3, page 10), triangulation of evidence types is more than sufficient, thus improving the reliability of the findings (Eisenhardt 1989; Yin 1994). It is however noteworthy that the majority of evidence originated from or was co-created with two informants, the maintenance solution manager and the data analysis specialist. Considering the holistic nature of phases one and two and the available resources, the close co-operation with the two informants was the most resource-efficient way to gather rich holistic evidence with access to specific details when necessary.

Further it is to be noted that the thesis instructor actively participated in the workshop and results discussions. As he was familiar with the work done, he was able to provide fresh perspectives and act as a devil's advocate when needed. This should be seen as a form of investigator triangulation, further improving the reliability of the findings (Eisenhardt 1989).

2.3 Practical execution of the study

The research process was highly iterative and time consuming, as could be expected with research of exploratory nature. The recommended duration for a master's thesis is 6 months, when working full-time. However, a Master's thesis typically takes 8-9 months, which also was the case for this study. Apart from some additional duties, I was able to work with the master's thesis full-time from the beginning of 2012, adding up to a total of 8 months of work by the end of October, when subtracting the vacations.

Converted to hours of work, a thesis is expected to take roughly 800 hours to complete. This objective was overshot with roughly 20-25%, much of which was due to the decision to extend the study with a quantitative analysis on service data. The decision to extend was made based on the perceived ratio between additional work and added value. This should however also be interpreted as the correct decision considering the chosen methodology, as "a case study is not likely to be complete if the study ended only because resources were exhausted, because the investigator ran out of time, or because he or she faced other, non-research constraints"(Yin 1994, p.149). The research process projected against a timeline is depicted in Figure 3 on page 13, complete with data collection events and major milestones.

In the fall of 2011 extensive preparatory work was done in order to find a match between academic interests, company interests and researcher competences, and despite only briefly mentioned in the background section, this work had a profound impact as it ensured a viable project. This reconnaissance phase ended with the case company selection at the end of November 2011. In December 2011 the study was designed and data collection was initiated, however, other projects were still competing for attention.

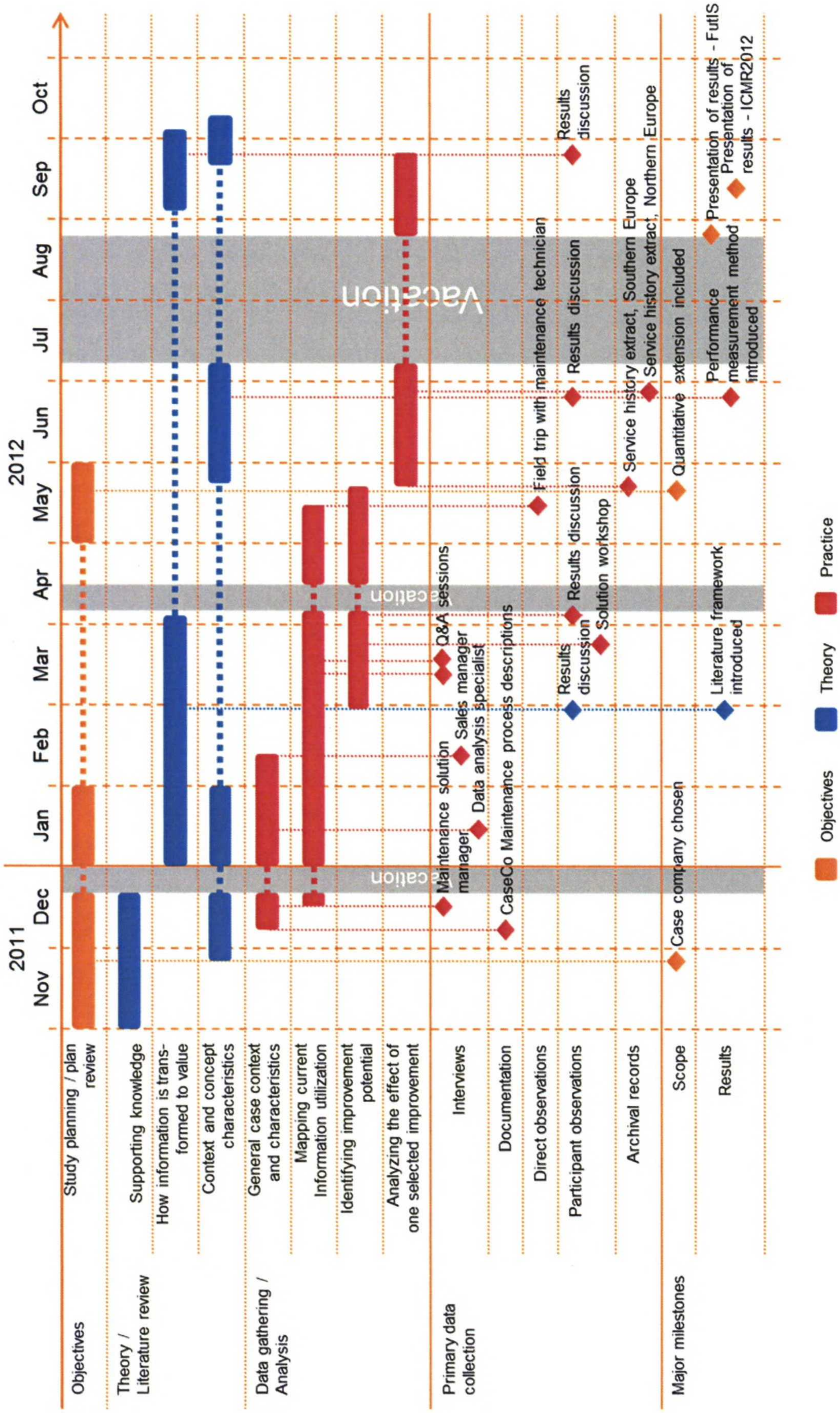

Figure 3 - Research timeline

The study kicked off in the beginning of 2012 with concurrent data collection, literature review and framework development. By the end of February, a first version of the literature framework was complete, and while the work on the framework continued, this allowed moving into identifying improvement potential through the framework. By the end of March a number of improvement suggestions were developed, and plans for a quantitative analysis started forming.

In the middle of May, the concrete decision was made to extend the study, accompanied by the delivery of the first data set. This also shifted the focus on the selected improvement suggestion, which was to be evaluated through the data analysis, leaving the other improvement suggestions on a conceptual level. By the end of June, the performance measurement method resulting from the quantitative analysis was introduced, and subsequently another set of data was delivered to further test the method.

The reporting practices at the FutIS-program called for the results of the study to be presented several times at different stages of the research. Two presentations however should be considered as milestones in the thesis process, namely the FutIS results seminar presentation on the 22nd of August 2012 in Espoo and the International Conference on Manufacturing Research (ICMR2012) presentation on the 11th of September, in Birmingham, United Kingdom (see Arhippainen et al. 2012).

In the next section we will look more closely on the dependencies between different parts of the study and how they form the main deliverable, the Master's thesis.

2.4 Structure of the study

In this section I will present the structure of the study, and how it was formed. The structure is illustrated through a combined process- dependence chart (Figure 4 - Study structure, page 15) lining out how the objectives of the study were converted to contributions.

The four central parts of the thesis, the literature review (section 3), and the analysis phases 1, 2 and 3 (sections 5, 6 and 7, respectively), are complemented with a section (4) describing the general context characteristics of the case (which naturally directed the theoretical exploration of the context (subsection 3.2)). The introduction builds a foundation for the thesis through describing the motivation behind the work (section 1), and the research setup section describes the methodological foundation which allows us to evaluate the validity of the results and propositions (section 2).

After the analysis sections, in the discussion section (8), the study is juxtaposed with current research in different fields. The implications of the research are addressed to the extent that they can be generalized, and the validity of the research is revisited. Further, some general managerial recommendations are presented. After the discussion, in conclusions (section 9), the contributions and their practical implications are crystallized and further research needs are lined out.

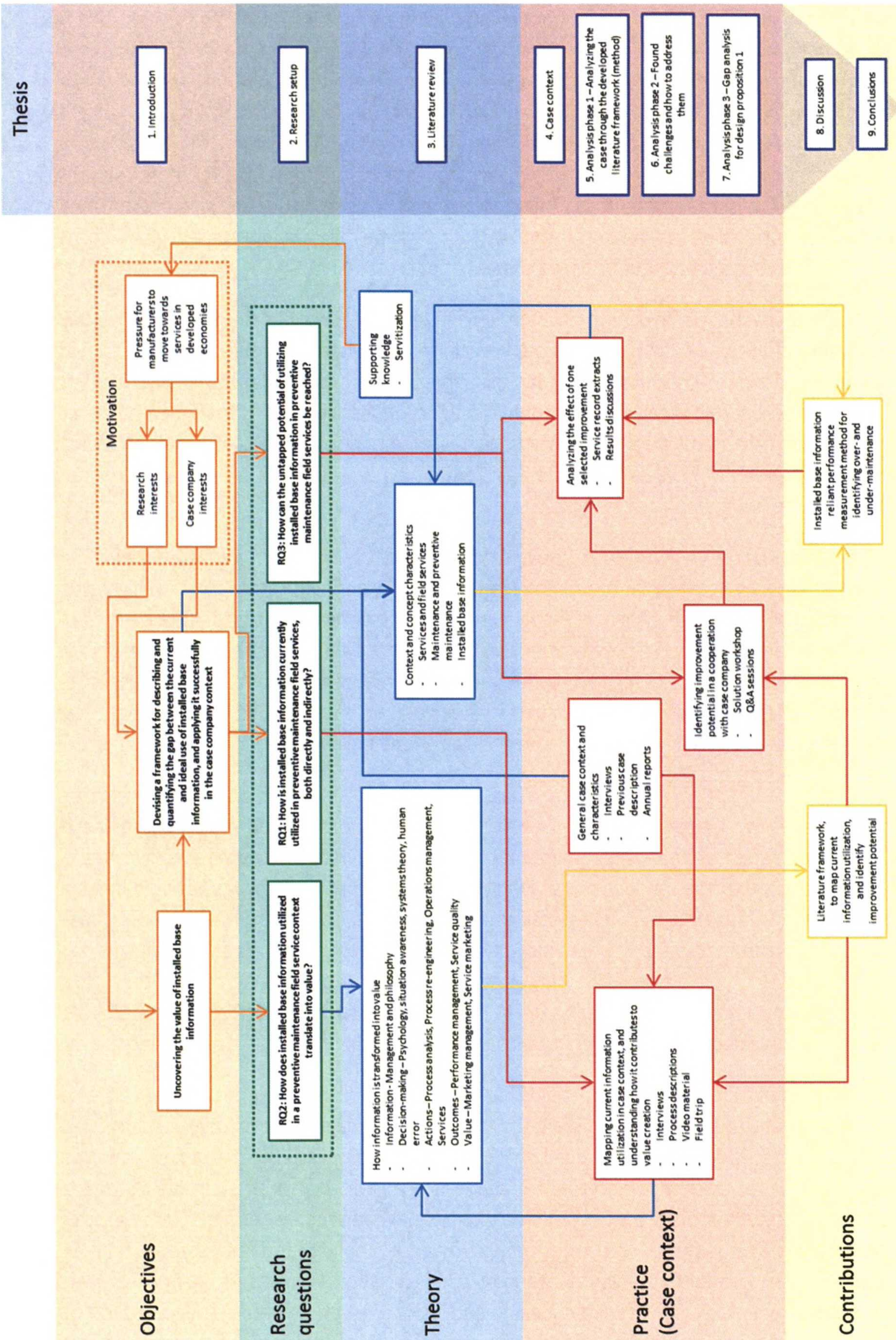

Figure 4 - Study structure

The objective of the study was to uncover the value of installed base information. This is directly translated to the second research question (RQ2: **How does installed base information utilized in a preventive maintenance field service context translate into value?**), with the addition of the context. RQ2 was tackled through the synergistic process described earlier, where theory gave impulses on where to direct focus in practical research, and the findings from practice gave impulses on where to look for more relevant theory. This iterative progression finally converged in a literature framework on how information translates to value (subsection 3.1). Described in the literature review, this is one of the central contributions of this thesis.

The approach for achieving the stated objective was also defined, to facilitate case company interests in the study. The approach sets requirements that the study should result in a framework, and that the concept and context (where the framework applies) needs to be defined. While these requirements are quite obvious, the approach further requires that the framework should; be tested, be able to describe the current situation, be able to describe an ideal situation, be able to describe and quantify the gap in a relevant measure, be useful and applicable.

The first research question (RQ1: **How is installed base information currently utilized in preventive maintenance field services, both directly and indirectly?**) arises from the requirement that the framework should be able to describe the current situation. While this was an important part of addressing RQ2, in the iterative process described above, RQ1 has the important function of setting the baseline against which potential improvement in information utilization is later evaluated. Needless to say perhaps is; that RQ1 was addressed through applying the framework developed when addressing RQ2, in a co-dependent progression.

The third research question (RQ3: **How can the untapped potential of utilizing installed base information in preventive maintenance field services be reached?**) arises from the requirements that the framework should be tested and that the framework should be able to describe and quantify a gap between the current and the ideal. RQ3 was tackled in the second and the third phase of the study, where the second phase was a solution spotting (effectuation) exercise (cf. Goldenberg et al. 2001; Sarasvathy 2001), realized through a researcher facilitated workshop. Then, in the third phase, one of the most promising solutions was selected for detailed analysis to satisfy the quantification requirement.

The gap-analysis of the selected solution (the third phase of the study, section 7) also guided the literature review regarding the context and concept characteristics (subsection 3.2), in an attempt to utilize and build on existing theory. The result of the detailed analysis was not only practically relevant, but resulted in the second central contribution of the thesis. The solution spotting process forms a bridge between the first and the third phase of the analysis as it is presented in this thesis, while the above mentioned contribution, an installed base information reliant performance measurement method for identifying over- and under-maintenance, is described and tested in the third phase of the study, section 7.

3 Literature review

Before initiating the work with the thesis, I participated in several researcher meetings and workshops[12] where the theme was directly or indirectly related to the value creation of information. An early observation was that in discussing the value of information, the word utilization was often used to depict the transformation process. This served as an important starting-point, as this implies that information per se does not create value, but it has to be used in some way in the given context for it to create value.

The word utilize however, seemed far too simple to describe the presumably complex dynamics underlying the transformation of information into value. The word utilize is defined as[13] "make practical and effective use of", therefore actually saying nothing about how the information is utilized, but only stating that it is used to advance the objective which is sought through its usage (effectively). This seemed as something which needed to be defined more explicitly.

This led me to looking more closely at the processes involved, as this seemed to be the most logical place where information would actually be utilized. While there might be situations where simply possessing the information could be considered valuable, the value in all situations is linked to a process or action at some point of time[14]. This led to the initial hypothesis which stated that information is utilized in processes which create value.

This facilitated thinking to a certain degree, implying that an important aspect of understanding how information contributes to value-creation, is in understanding how information is used in the processes which create the value. However, the initial hypothesis proved to be problematic as it sparked further questions, namely; how is information utilized in processes and how do processes create value? The answers to these questions were found in the process analysis literature.

We begin by looking at the central theme of the thesis, namely, what existing literature has to say about how information translates to value (subsection 3.1). Based on this first part of the review I will also present five identified constructs, which form the basis for the analysis of the case in its context. In the second part (subsection 3.2) of the literature review we will take a closer look at the context where the analysis is performed. I will present relevant aspects of installed base information, preventive maintenance and field services covered by existing literature. Finally, in subsection 3.3, I will sum up the key points extracted from literature to support the subsequent analysis

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12 Within the FutIS program, work package 3
13 According to the Oxford online dictionary (retrieved May 5, 2012) – http://oxforddictionaries.com/definition/utilize?q=utilize
14 Having a service log for your car will surely increase the resale value of it, implying that information per se is valuable. However from the byers perspective, the service log increases knowledge of the history of the vehicle and might also increase the level of trust that the equipment has been cared for by its previous owners. In other words having the service log reduces risk and uncertainty regarding the necessity of future repair actions, effectively tying the information to action.

3.1 On how information is transformed to value

A process is always triggered by something (Jacka & Keller 2002). These triggers may be, but are not limited to service provider decisions, IT-system decisions and customer decisions. The common denominator being that triggers are decisions or requests to act based on a perceived demand for the process to be executed. Thus the original hypothesis is refined through the addition that information is utilized in processes through decision-making.

Further, when we explore the nature of processes, we discover that the term is used to describe a group of tasks or activities arranged in a logical order to achieve a stated objective (Davenport & Short 1990; Hammer & Champy 1993; Jacka & Keller 2002). From this we can conclude that every activity within a process should have a reason for its existence, every task should be necessary (Jacka & Keller 2002). The set of tasks needed for achieving an objective is determined when the process is designed. In other words, based on information available at the point of time when the process is created, there is a decision to include an activity into the process, effectively embedding a trigger for that activity within the process. Thus, decisions, which use information, do not only trigger processes, but they also define processes.

The link between processes and value is also far from straight forward, as it is complicated by the subjective nature of value. If we consider the process as a transformation of an input into an output, which is desired by the customer (Jacka & Keller 2002), we strike an important note. It is the output which is desired by the customer, while the process is synonymous to the transformation. When we flip it the other way around, it becomes obvious; if the output is equal to the input, or if no transformation has occurred, then no value has been created.

The words input and output originate from industrial process design, and are commonly used when describing closed systems. Service processes are however always to some extent part of open systems due to the co-creating role of the customer (Sampson 2000; Sampson & Froehle 2006). This complicates the control and measurement of processes, introducing a resident degree of uncertainty. Thus it would seem as if the word outcome is better suited for describing the link between the process and the value in the case of service processes.

To sum up, we end up with five main constructs (Figure 5, below) which are needed in explaining how information is transformed into value: Information is used in decision-making, which triggers and defines actions. Actions produce outcomes, which are changes in the state of the object of the action, as well as information, which is again used in decision-making. Value is then determined by the stakeholder, based on the outcome's impact on the stakeholder. The rest of this section will widen the literature framework around the "bone" described below. The case analysis is then carried out through building a network representation of the focal process using the developed literature framework.

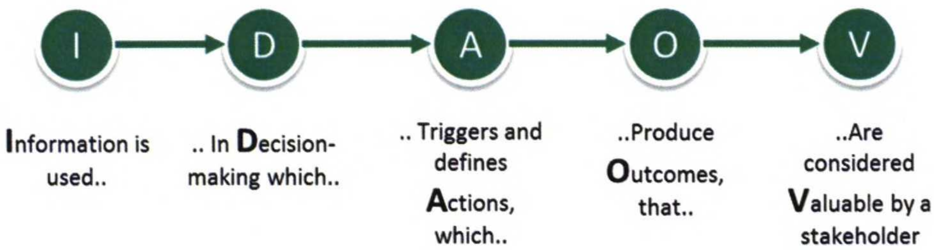

Figure 5 - The transformation of information into value

3.1.1 Information

The concept of information is used in a variety of fields and consequently defined in many different ways. Depending on which field is in question, the concept of information may emphasize different ends of the sequential chain where a phenomenon is observed, interpreted, assimilated as knowledge and used in directing action. Here the harder sciences tend to attach the requirement of objectivity to information, where information is a representation of form or state obtained by measurement. Where again human-centered approaches to information emphasize characteristics such as meaning and use, implying that information is not exact and absolute, but rather what is believed to be true and real. (Losee 1997)

Losee (1997) refers to the Sesame street character "Cookie monster's" definition of what information is, being "news or facts about something". In this definition he identifies what he calls common notions that information must:

- Be something, although the exact nature (substance, energy, or abstract concept) is not clear;
- Provide "new" information: A repetition of previously received messages is not informative;
- Be "true:" A lie or false or counterfactual information is misinformation, not information itself;
- Be "about" something

I shall agree with these fully, except for the second item, as I argue that the fact that a certain piece of information has remained unchanged actually is new information[15]. For the purpose of this thesis we will prefer to study the human aspect separate from information, so we will define information as *an observation of a specifiable state or dynamic property of reality*. This definition allows three different types of information (Figure 6, page 20); the state of reality, how reality has changed, and how reality is changing. This definition is well suited to describe a complex system (cf. Simon 1962 on the duality of state and process), which *reality* undoubtedly is.

[15] Consider two situations, the first where you learn that a dog is called Fluffy, then repeating this information after two years could hardly be seen as new information, provided you still remember the name of the dog. The second situation where you learn that the mileage of a car is 30000, then repeated after two years for the same car, despite being the same information, 30000, the information is new, because it implies that the car has not moved since.

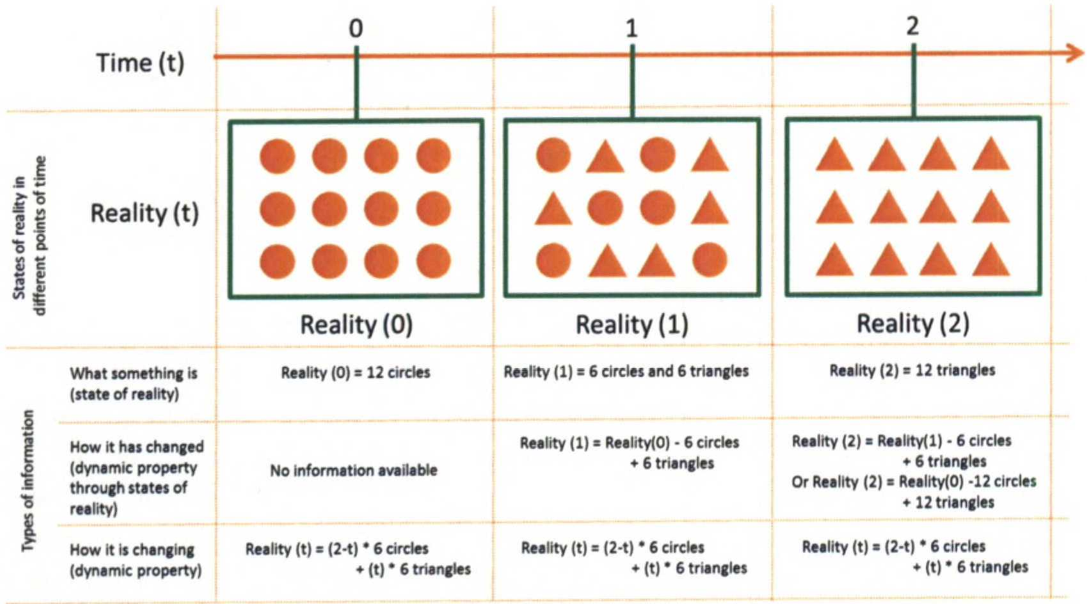

Figure 6 - The different types of information

Based on this definition, information has three features which are relevant when analyzing the transformation of information to value. Derived from the *state of reality*, information is by definition a representation of a hierarchical layer, meaning that depending on the perspective, information is instance in a group as well as a basis for aggregation of a specific group (see Table 4, below). The combination of *state or dynamic property* implies that information changes over time, which means that information in its stable form has a lifespan, and that the evolution of the state is reflected by comparison of several state representations, this in turn implying that information on a higher level than the changing state has a frequency on how often the state changes. The third feature is to be found where *dynamic property* is detached from the state to describe the behavior of the higher level of information, typically defined through other states of reality, for instance the laws of physics. This third feature will sometimes allow us to substitute information for simpler or more accessible information. (cf. Simon 1962)

Table 4 - The hierarchical nature of information[16]

Problem (decision)	Prerequisite knowledge	Hierarchical level (of information)	Information	Relationship to adjacent levels	Solution (rationale)
Should I bring an umbrella?	Where am I?	Strategic	It is autumn	The seasonal weather fluctuation due to earths tilt and elliptic orbit around the sun, combined with the proximity of the Atlantic ocean	I will bring the umbrella, because it is most likely to be useful this time of year

[16] Included here to illustrate the principle only, not intended as an accurate description of the information underlying the decision to bring an umbrella.

				causes rainier weather than average	
	How has the air pressure changed?	Tactical	Air pressure is dropping	Dropping air pressure is a measure of atmospheric dynamics, and an indication of an approaching weather front which means rainy weather is imminent	I will bring the umbrella , because I can expect that I will need it
		Operational	It is raining outside	You are at a location currently experiencing rainy weather.	I will bring the umbrella, because otherwise I will get wet

As we move on to decision-making, we'll do well in remembering that the *state of reality* is a theoretical concept. The state of reality perceived by any (human) observer is actually a mix of past and present states of reality as we're able to observe only so much any given second (Sterman 2000). It is then through these accumulated observations that we build our holistic (but mostly historic) perception of reality.

3.1.2 Decision-making

Even if today's information-rich society might be perceived to appreciate information for the sake of information, the value of the time spent searching for, assimilating and understanding the information is determined by how you act based on it (Simon 1997, chap.2.4). A business-environment is no different from society in this sense, where decision-makers within organizations use information on a daily basis in deciding upon what actions to take (Thompson 2003; Simon 1997). Or as Forrester (1992, p.56) put it inversely: "The ever-advancing present moment in decision-making is the businessman's and politician's world of action". Decision-making is a widely studied subject, and in the following I shall synthetize four views; organizational psychology, human error, situation awareness and systems theory, with very similar, but at the same time unique and complementing characteristics.

So, when are decisions needed? When is there a demand for decisions? – It all starts with a situation, or per our definition of information, a state of reality. In this situation the decision maker (we'll leave this term open for now) perceives that a different state of reality is preferred (L. R. Beach & Connolly 2005). In order to achieve this different reality, a change in the current reality is required, and this constitutes the decision situation: how should reality be changed? The bigger the chunk of reality involved is, the more complex the decision per definition is (Milliken 1987):

- the more states affect the outcome of the change, and them being unknown, the more uncertainty is involved,
- the harder it is to grasp the involved dynamic properties,
- and consequently, the more alternative ways there might be to change the current reality (to act).

However, here we need to remember that reality is in a constant state of change, as we are not manipulating it alone. This constant state of change implies that even if we might see that there is a need of change in reality; reality might just be changing in exactly that direction. Thus, when there seems to be a demand for a decision, and the decision is actually to do nothing, it still has to be considered a decision as the choice of doing nothing is conscious. Thus we could also say that consciousness of the current and desired situation is what spawns decisions, and that there is, rather than a demand for decisions, a supply of decisions emerging from a continuous stream of conscious awareness of reality (Forrester 1992; Endsley 1995).

The difference between these two ways of looking at the emergence of decisions is fundamental. The demand view of decisions requires us to study the decision at a stable state of reality (in other words at a frozen point of time), while the supply view of decisions allows detachment from time. Thus we can shift from studying single decisions to studying how a decision maker acts in a changing reality. As we wish to understand how information is transformed to value in a continuous fashion instead of a time and current reality bound instance, we shift the focus from studying decisions to studying decision makers.

When dealing with complex decisions the typical decision maker faces limited access to relevant information, limited understanding of what information is relevant and a limited understanding of what actions are available that will produce the desired outcome. These limitations emerge from the accumulating "cost" of living with the current reality, effectively creating a limited time span in which the decision is to be taken (Simon 1955). This in turn implies that there in fact is an optimal level of awareness for every decision, a point where gathering more (state) information or increasing the understanding of the underlying dynamics is more costly than to make the decision based on the information already available (Simon 1959).

The human being as a decision maker has cognitive limitations in processing information, rising from the maximum capacity of the short-term memory at seven plus minus two "pieces" of information. The way to cope with this is through grouping information in a meaningful way. On a theoretical level this means that we are as likely to remember seven unrelated letters, as we are to remember seven unrelated words or seven unrelated sentences (Miller 1956). In complex decision settings this means that we make the problems we are facing manageable through grouping or aggregating information.

Where the this type of aggregation implies moving up in the hierarchy of information to create a sufficient picture of the state of reality, further help is needed when evaluating the dynamics of the relationships between these seven plus minus two pieces of information. For most managerial problems there is no "laws of physics"-type solution which would enable us to fully comprehend the involved dynamics. One way to approximate the involved dynamics is through using rules of thumb, which reduce the complexity of the decision-making situation to yield a pretty good decision quickly and easily based on simplified and incomplete models of the problem situation (Sterman 2000).

Further, the decision-making with respect to involved dynamics can be refined through learning[17] (Sterman 1994). If facing a similar decision over and over again we might develop a routine where the same course of action, which has been proven effective, is chosen (Sterman 2000). If the decisions can't be copy-pasted, we still benefit from experience (both personal and organizational) through developing policies[18], or decision rules (Reason 1990), which enable us to make an educated guess on what to do in similar situations (L. R. Beach & Connolly 2005, chap.3). Forrester's (1992, p.47) definition of policy is a bit broader as he includes the upcoming concept of framing in stating that "When we discuss reasons for action, we are describing policies whereby information is converted into action".

Although every decision-making situation arises from the current state of reality, the decision-making situation itself is perceived differently depending on the experiences of the observer. This perception, which is the act of making sense of the current reality through ones experience is referred to as framing (L. R. Beach & Connolly 2005, chap.2) or schema selection (Endsley 1995). The way we frame the state of reality in effect determine which rules and policies apply, and thus we are likely to arrive at different decisions depending on which frame we evaluate the situation through.

The act of switching between frames is subconscious at best, and is manifested in the way we tend to look at current states of reality through whichever frame the situation makes most sense (L. R. Beach & Connolly 2005). Framing within organizations has been proven a useful concept in studying adoption of new IT-systems (Orlikowski & Gash 1994), and Beach and Connolly (2005) point out that making collective decisions (leading to collective action) in organizations is essentially an effort to align the different frames that the decision participants (or subsequently performers of action) have.

Reason (1990, chap.5) presents the two principal situations where bad decisions arise from the use of policy. The first is misapplication of good policy, which implies that a well tried policy is applied in a situation where enough information on the state of reality seems to call for application of the policy, while omitted information later reveals that the policy was not applicable in the given state. The second is the application of bad policy which essentially boils down to ambiguity on in which conditions the policy may be applied and inadequacy of the solution suggested by the policy. Here the first situation can be interpreted as a problem with framing.

When policy is unable to produce a single outstanding alternative, we are forced into a more intricate decision-making process where more detailed analysis of the state and dynamics of reality produces the available alternatives for us to choose from (L. R. Beach & Connolly 2005). When doing this we effectively move into the realm of decision theory and

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[17] Assuming that we observe the effects of our decision

[18] Or schemas (Endsley 1995), or habits, or scripts depending on the field of study (L. R. Beach & Connolly 2005, p.32)

decision analysis, and thus the unit of study can no longer be the decision maker, but has to be reduced to a single decision in the context where it was made.

Before moving on to action, we will do well in reminding ourselves that despite the human centric approach to describing decision-making used here, most of the day to day decisions in modern business are taken by IT-systems (Simon 1997) based on predefined rules (or policies). This means that most decisions go by unquestioned[19], while being subject to the same errors as human made decisions. This however doesn't mean that the human decision maker would always question his or her policies, as is not the case for 43% of corporate workers according to a recent study (Shah et al. 2012).

3.1.3 Action

An important aspect when moving from making a decision to actually executing it is the time elapsed between the moment that the decision is made and the moment the action based on the decision takes place. The importance of this naturally arises from the constantly changing state of reality implying that the validity of the decision (possibly) deteriorates at the rate of which the information the decision is based on changes. Long timespans between actual decision and action can be found in IT-systems, where the decision logic is infused by programmers based on specifications, and in processes, where the decision logic is infused by the process designer. On the other hand, a process could also be seen as an explicit manifestation of policy.

The process, as mentioned in the introduction to this section, is a set of necessary activities, performed in a logical order to achieve a stated objective (Davenport & Short 1990; Hammer & Champy 1993; Jacka & Keller 2002; Aguilar-Savén 2004). The word process and action (or activity) will be used interchangeably for the purposes of this study, as they both are regarded as changes in the state of reality that are based on a prior intention to act (a decision), and resulting in a changed state of reality (or outcome) which either does or does not equal the intended or expected change.

Process, and by extension action, inputs can be for example energy, materials, labor, capital, information, customers, people and facilities (Slack et al. 2006, chap.1; Schroeder 2000, chap.1; Johnston & Clark 2008, chap.6). Based on the previously stated requirement for a successful process: that the output needs to be different from the input in order for a transformation to have occurred (Jacka & Keller 2002), we could argue that not all of these inputs actually are inputs. Aptly, Slack et.al (2006) makes a distinction between inputs that are transformed within the process and inputs that do the transforming[20].

In a service process one of the essential inputs is provided by the customer (Sampson & Froehle 2006), and can consist of the customer's self, his belongings or other tangible objects and information (Wemmerlöv 1990). Related to the transformation requirement stated above, Wemmerlöv (1990) further makes a distinction between transforming and handling goods, and between processing people and information. With this in mind, the

[19] "We've tended to forget that no computer will ever ask a new question." -Grace Hopper, discoverer of the first computer "bug" (Schieber 1987)

[20] Also compare this to the distinction between operand and operant resources, in the service-dominant logic (2004)

concept of transformation becomes ambiguous. When moving from goods to services, we are effectively broadening the concept of transformation to include dimensions such as location, time and, for the lack of a better expression, emotions and awareness.

This is in strong contrast to the common expressions of process or action outputs, which are expressed plainly as goods or services (eg. Slack et al. 2006, chap.1). However, Schroeder (2000) notes that part of the output is information which is used in controlling process inputs and technology, and Jacka and Keller (2002) adds that waste (in a broad sense) is also an output despite being unwanted. Further, they propose that outputs cannot be fully controlled, as there will be surprises and invisible (long-term) consequences.

The ability to control action correlates with the degree to which the process or activity is isolated from environmental[21] influence. The higher the influence of the environment on the inputs and the process itself, the more variation can be expected in the output (Thompson 2003). As previously stated, outcomes is a more suitable term for outputs in the case of services. In the next section we will look at the role of outcomes, effectively allowing the right thing to be done while producing the wrong result and vice versa.

3.1.4 Outcome

Outcomes serve as the link between supplier and customer, as the outcome is the difference between the state of reality before and after the action was performed. For a business relationship to exist there needs to be an aligned interest between the supplier and the customer to change the state of reality. Another precondition for a business relationship to exist is that the supplier has an advantage in executing the change through action (in the case of services, in co-operation with the customer), compared to the customer making the change on its own. Value from both the customer and the supplier viewpoint, is determined by the outcome and how it is reached.

In reaching the desired outcome there is a possibility that errors are introduced in the steps preceding the outcome. Reason (1990, p.9) defines the error as "all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency". If we define success through value being created, the outcome has a pivotal role, as in coherence with the definition of errors; an intervention on the state of reality is successful from the customer's point of view, as long as the poorly executed action initiated by the flawed decision based on faulty information results in the intended outcome.

While this constitutes doing the right thing, doing things right is about the opposite. Here, again in coherence with the definition of errors; the flawless action initiated by the logical decision based on correct information might result in an undesired outcome due to chance, but is likely to result in the desired outcome, thus determining success of the intervention from the supplier's point of view. The latter is well represented in the performance measurement and management literature, which has only recently moved beyond the bounds of the focal firm (Folan & Browne 2005).

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[21] Here used in a systems theory meaning

Despite a strong manufacturing influence, Kaplan and Norton (1992) emphasize the importance of integrating the customer viewpoint into performance management. Through a case they underline the importance of understanding what the customer values and how this perception varies among customers. With outcomes being the link between actions and value, it is these changes in the state of reality which we need to measure in order to make sure that we are doing the right things.

Distinguishing between doing the right things and doing things right, or what is done vs. how it is done, is not new. Grönroos (1990) presents these as the dimensions of service quality, adding that the outcomes, or what is done (technical quality), is easier to evaluate objectively than how it is done (functional quality). Reverting to our definition of action and supported by our coming discussion on value, I argue that the functional quality can be refined to technical quality through studying the action in more detail and breaking down processes to tasks. However, this does not necessarily imply that it will become easier to evaluate.

3.1.5 Value

The concept of outcomes per our definition allows itself to be organized in a hierarchical manner, where a number of outcomes can be grouped, for instance based on what is being transformed in the action. In other words, we can, in the case of industrial services separate the outcomes for the customer's equipment, people and information. These individual outcomes can be independently evaluated by the customer, and as combined they form the perception of value (Vandermerwe 2003).

Value is an elusive subject as it is typically defined using terms such as utility, worth, benefits and quality, which are (almost) as subjective and ambiguous as value itself (Woodruff 1997). An important distinction on how value is perceived is expressed as the goods- and the service-centered dominant logic (Vargo & Lusch 2004):

- Goods-centered dominant logic implies that the value is determined by the producers. It is embedded in the operand resource (the good) and is defined in terms of "exchange-value"
- Service-centered dominant logic implies that value is perceived and determined by the consumer on the basis of "value in use". Value results from the beneficial application of operant resources sometimes transmitted through operand resources - firms can only make value propositions.

Woodruff's (1997) definition of customer value could be interpreted as bridging these two different perspectives as he states that "Customer value is a customer's perceived preference for and evaluation of those product attributes, attribute performances, and consequences arising from use that facilitate (or block) achieving the customer's goals and purposes in use situations". This definition however (undoubtedly due to a product centric premise) lacks the implications of service-centered dominant logic that value is not only defined by the customer, but also co-created with the customer (Vargo & Lusch 2004; Sampson & Froehle 2006).

The customers perception of what is valuable is constantly changing (Grönroos 1997), which implies that creating and nurturing customer relationships is essential in keeping up with the changes (Anderson 1995). Furthermore, as relationships develop, even the supplier's perception of value in the relationship might change due to greater appreciation of indirect value-creating functions[22] (Walter et al. 2001).

The ambiguity of value suggests that performance measurement based directly on value is challenging, however for a comprehensive view on how the business is performing, the customer view is an essential component (Kaplan & Norton 1992). Where value itself is difficult to measure, outcomes are likely to be more easily measured thus providing the closest measure to value available, assuming that you are able to measure whether "the right things are being done".

3.1.6 The literature framework

The five constructs elaborated in the previous sections are the fundamental building-blocks of the literature framework. The framework is applied through mapping the focal process using nodes corresponding to the five identified constructs (Figure 5, page 19). The resulting network representation (Figure 7, below) is then inspected from a (system-) dynamics point of view, while being aware of the characteristics of each of these constructs. In this study the focus is on the preventive maintenance process, however, the mapping could equally be done from an information-, decision-, outcome- or value- point of view.

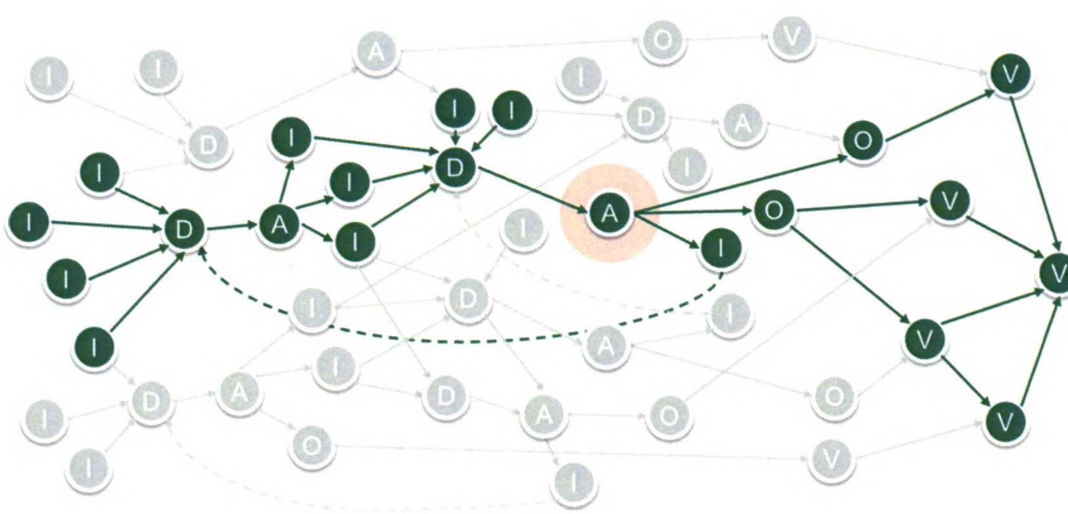

Figure 7 - A Network representation with a focal process or action

The generic properties of the constructs gain meaning only when they are applied in a context. In other words, the context where the literature framework is applied imposes unique rules and characteristics when considering the dynamic properties of the network. Thus, we will continue with a concise and relevant description of the empirical context of the study.

[22] For example market access, technological know-how, etc.

3.2 Empirical context of the study

In this section I will present the relevant characteristics of the study's empirical context extracted from existing literature. As we will later analyze the focal process in the case company through the literature framework presented in the subsection 3.1, I will attempt to relate the presented context characteristics to the five constructs (information, decision, action, outcome and value) of the literature framework.

As mentioned in a couple of occasions in the previous section, there are certain characteristics in services (versus manufacturing) which have a significant impact on how the dynamics between the constructs play out. We will continue the discussion on services and more specifically field services in subsection 3.2.1. In subsection 3.2.2 we will take a closer look at the nature of the focal process, which is preventive maintenance. Finally in subsection 3.2.3 we will analyze how the particular interest of this research, namely installed base information relates to the five constructs and their interrelationship.

3.2.1 Services and field services

When venturing for a definition of services one is bound to find himself on thin ice. One of the more persistent definitions is the IHIP-definition, which states that services are characterized by intangibility, heterogeneity, inseparability and perishability. The applicability of this definition has been criticized by many (cf. Vargo & Lusch 2004; Sampson & Froehle 2006), while its persistence, indicating its usefulness, cannot be ignored (Moeller 2010). Moeller (2010) proposes a solution for the ambiguity surrounding the definition by tying the four characteristics together with different stages of service provision.

In her model Moeller (2010) ties the perishability and heterogeneity characteristics with the facilities required for service provisioning. The term "facilities" is here used in a broad sense to depict service provider resources (which are characterized by perishability) and customer resources (which are characterized by heterogeneity) that are joined in the transformation phase[23]. Further, in the transformation phase the customer resources are transformed by the supplier resources (which leads to inseparability), initiated by the customer demand meeting the suppliers offering (which is characterized by intangibility).

Field services constitute the special case where it is usually more convenient for the supplier resources to move to the customer site for the inseparable service production instead of vice versa. An exception to this, while still going under the term field services, is services which are provided electronically, which encourages us to keep an open mind on what "moving" to the customer site means[24]. A subcategory of field services is after sales services, which encompasses support of delivered equipment[25] through installation, maintenance and repair. (Agnihothri et al. 2002)

[23] To my understanding Moeller (2010) uses the word resources in a way which is interchangeable with the word inputs according to how inputs were implicitly defined earlier

[24] In this case the inseparability is not bound to physical objects, as the customer inputs themselves are not of a physical nature. However, inseparability in time is still likely to apply.

[25] Implying that it is more convenient for the service supplier to perform the service on-site, than it is for the customer equipment to move to a centralized service provisioning facility.

Table 5 - The installed base service space (applied from Oliva & Kallenberg 2003)

	Product-oriented services	**End user's process-oriented services**
Transaction-based services	**Basic installed base services** Documentation Transport to client Installation/commissioning Product-oriented training Hot line/help desk Inspection/diagnosis Repairs/spare parts Product updates/upgrades Refurbishing Recycling/machine brokering	**Professional services** Process-oriented engineering (tests, optimization, simulation) Process-oriented R&D Spare parts management Process-oriented training Business-oriented training Process-oriented consulting Business-oriented consulting
Relationship-based services	**Maintenance services** Preventive maintenance Condition monitoring Spare parts management Full maintenance contracts	**Operational services** Managing maintenance function Managing operations

In the case of after sales service the basis for the demand is a capital good, which has been sold to the customer. Depending on the service supplier's capabilities, it can offer either transaction- or relationship-based services focused either solely at the capital good in question or alternatively broader at the process or system part of which the good is (see Table 5, above). While service suppliers often are eager to provide services both to their own delivered goods and to competitor delivered goods, there are unique advantages when serving the former (Oliva & Kallenberg 2003).

Relating this to the literature framework presented in 3.1, the general service characteristics mainly have implications for the service process, or action inputs and for the transformation process itself. As our context is a specific (product-oriented, relationship-based) after sales service offered by a capital goods manufacturer, intangibility of the offering is indirectly linked to the outcomes through service agreements. In field services, and more specifically after sales service delivery, the role of information related to the customer asset is crucial, as it can be used to increase the quality and efficiency of service delivery (Ala-Risku 2009). Further, when moving towards advanced relationship-based, process-oriented services with value-propositions tied to customer business objectives, the need for intimate knowledge on the customer operation grows (Mathieu 2001).

3.2.2 Maintenance and preventive maintenance

Maintenance has been studied thoroughly in the manufacturing context, and while it (from our viewpoint) represents the asset management (or customer) viewpoint, we shall find several useful concepts here. Kelly (2006, p.26) defines the function of maintenance in a manufacturing environment as "to sustain the integrity of the physical assets by repairing, modifying or replacing them as necessary", which could also be expressed as "to provide and control the reliability of the plant". Further the maintenance strategy of the firm should be tied to the firm's business objectives in a manner which enables maintenance strategy deployment on the level of equipment individuals[26] (Kelly 2006).

Maintenance activities can be divided into reactive and proactive, where reactive deals with equipment failures, and proactive intends to prevent them. There are different maintenance management methods, also commonly referred to as maintenance strategies or policies, which can be applied on both aggregate and equipment instance level[27]. These different strategies typically have several different definitions due to overlapping terms. The different maintenance strategies according to Mobley[28] (2002), complemented with Kelly (2006) are:

- **Run-to-Failure** (also known as "operate-to-failure"), which implies a reactive maintenance strategy where maintenance actions are performed only when the equipment fails. However, this type of strategy is usually accompanied with some preventive elements (i.e. lubrication and adjustments) where applicable. In a RTF maintenance strategy the resources on standby have to be proportional to the impact of the failure, which excludes the RTF strategy from most high failure impact (economic, environment and safety) equipment.
- **Preventive maintenance** (also known as "fixed-time maintenance"), which is, despite being defined in many different ways, always based on fixed intervals (either according to age, calendar or usage). The extent to which preventive maintenance is performed ranges from simple lubrication and adjustments to part replacement depending on context (often equipment criticality). As the preventive maintenance scheduling is based on reliability statistics (see Figure 8, page 32), there is bound to be some over- and under-maintenance. The availability of statistical data is a prerequisite for this type of maintenance, which implies that the quality of data is directly related to the quality of the maintenance plan.
- **Predictive maintenance** (also known as "condition-based maintenance"), which is based on actual equipment condition obtained through continuous monitoring[29]. Predictive maintenance aims at maximizing the maintenance intervals while minimizing failures through performing the maintenance actions when indications of an impending failure arise. Another key characteristic of predictive maintenance is dealing with problems in a timely manner after the deterioration-phase has been initiated. This should be considered valuable as, even if you manage to avoid a failure, a late intervention can be expected to lead to higher repair costs[30] (cf. Kelly 2006, fig.5.12).
- **Opportunity maintenance**, which actually is more of a scheduling procedure than a maintenance strategy, but still worthwhile mentioning as it tends to override other

[26] This approach and procedure is coined business-centered maintenance. While this is a clear top-down approach, it forms an interesting contrast with the traditional bottom-up reliability centered maintenance approach.
[27] For a decision logic on identifying the best maintenance policy, see Kelly (2006, fig.6.20)
[28] Note that as Mobley (2002) has a significant predisposition towards presenting predictive maintenance in a favorable light, I've tried to apply a strict lens of objectivity.
[29] For example vibration monitoring, visual inspection, thermal imaging and lubricating oil analysis. For a comprehensive summary of available techniques, see Kelly (2006, pp.109–112)
[30] For example spare parts, more maintenance work and consequent problems in related systems

strategies. Opportunity maintenance implies that the timing of the maintenance actions is determined by some other event, due to convenience and availability maximization reasons. This type of maintenance is common in the process industry, and is done for example in connection to a power plant statutory boiler inspection or a steel mill blast furnace overhaul.

- **Design-out maintenance**, which aims to eliminate the cause and need for maintenance altogether. Design-out maintenance could be characterized as complementary strategy, or as a backup strategy, which is the last resort if other strategies produce unsatisfactory performance. This strategy naturally moves partly outside the maintenance function, but if applicable it might be a preferable strategy.

While I for the most part agree with Mobley and Kelly on these definitions, I argue that the line between preventive and predictive maintenance is ambiguous at best, and that any given preventive maintenance strategy will contain predictive elements and vice versa[31]. Further we could argue that while there are certain maintenance activities (such as lubrications, adjustments etc.) which are clearly preventive, a more relevant base for definition is how the demand for maintenance is stated or verified. Excluding the obvious case of "failure has occurred" Kelly (2006, fig.6.20) presents three fundamental approaches to stating or verifying the demand for maintenance in the case of normal items[32]:

- Online and offline failure detectability, depending on if the condition of the equipment can be confirmed while it is in operation, or not. Condition monitoring in its various forms falls into this category. Condition monitoring can be accomplished in three main ways (Kelly 2006, p.107):
  - Simple inspection: Mainly qualitative checks based on looking, listening and feeling (e.g. to detect rope wear). The period between inspections should be adjusted according to target failure lead-time.
  - Condition checking: Done routinely by measuring some parameter which is not recorded but is used for comparison with a control limit. Such checking only has value where there is extensive experience of identical systems.
  - Trend monitoring: Measurement and graphic plotting of a performance or condition parameter in order to detect gradual departure from a norm. This application is most effective where little is known about the deterioration characteristics. When enough knowledge of these has been acquired, condition checking can be substituted for trend monitoring.
- Statistical failure predictability, where the typical failure-rate distribution over time, for the part or the equipment in question, is known. An example of this is the classical bathtub curve which has become a popular generic case within reliability engineering (Klutke et al. 2003) (see Figure 8, page 32).

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[31] For example a preventive maintenance action is bound to have elements of visual inspection while lubrication is likely to be done on a time-basis despite a predictive maintenance approach.

[32] As opposed to special items for which the failure is not observable under normal operating conditions (hidden failures), for example safety related equipment and parts.

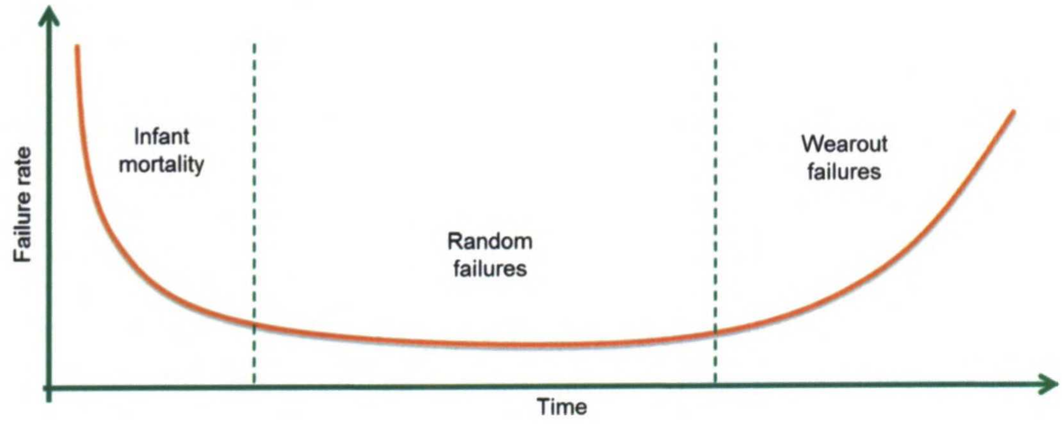

Figure 8 - The classical bathtub curve

While different types of parts and systems have shown failure-characteristics which can be found in parts of the bathtub curve[33] (Bennett & Jenney 1980), the usefulness of the bathtub curve has been questioned due to the lack of compelling empirical evidence, especially in the infant failure region (Klutke et al. 2003). While the failure-rate distribution of complex systems could be expected to be more random by nature (Murthy et al. 2008) (as the reliability of the system is directly tied to the reliability of its parts), the important contribution of the bathtub curve is that, environmental and usage factors put aside, we are dealing with three principal types of technology based failures; wear in, wear out and random.

Factors affecting the reliability of equipment include the underlying technology, environment, usage and maintenance actions (Murthy et al. 2008, chap.4). While a piece of equipment is designed for a certain purpose, to be used in a certain way in a defined environment, there is bound to be variations in the implementations. This could be seen as one of the main challenges of utilizing statistical failure predictability in field service operations. If mastered however, great gains can be untapped (cf. Golabi et al. 1982), and the foundation for a competitive advantage established (Beckman & Rosenfield 2008, chap.9).

Finally, the concept of failure lead-time is crucial in all types of proactive maintenance (Kelly 2006, chap.6). The failure lead time is essentially the time it takes for a failure from the instance it starts developing to when it prevents the equipment from performing its intended function. Further failure gradually becomes visible to condition monitoring, service engineers and users. The notion here is quite obvious, in that if the failure visibility (when the failure is detectable) exceeds the time interval at which the condition of the equipment is checked, the failure will on average be prevented[34] (see Figure 9, below).

[33] For example a decreasing failure-rate for electronic components (which could be seen as indicative of infant failures), and an increasing failure-rate for hydraulic components (which could be seen as indicative of wear out failures.

[34] Assuming that the lead-time is seen as a probability distribution

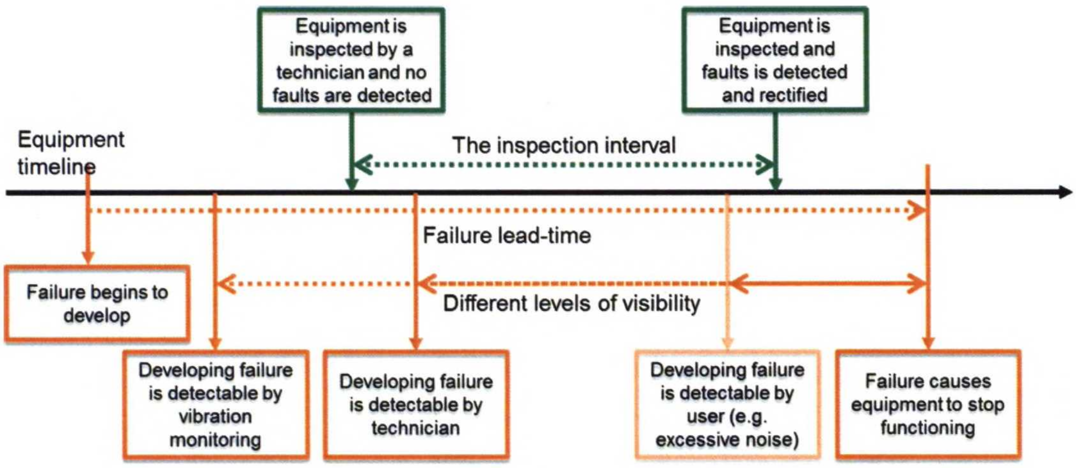

Figure 9 - Failure lead-time and visibility

The different levels of failure visibility are of course equivalent to failure detectability, and play a major role in selecting the proper proactive maintenance strategy. Failure detectability by users seems to have some untapped potential due to scarce literature on the subject. However, the concept of user-driven maintenance (or autonomous maintenance) is one of the key components of Total Productive Maintenance (TPM), where it goes beyond detecting failures to executing some aspects of the maintenance work (Nakajima 1988; Troyer 2006; Hykin 2005).

The preventive maintenance process, which is the focus of this study, has characteristics of both preventive and predictive maintenance, according to how we have defined them here. Reflecting this subsection to the five constructs, we have mostly discussed the characteristics of actions, how they are triggered and how they relate to measurable outcomes. Further we have established that the more and better information you have, utilized correctly in decision-making, the less you are likely to under- or over-maintain in all types of proactive maintenance.

3.2.3 Installed base and installed base information

The term "installed base information" can be rewritten as "information on the installed base" without changing its meaning. As we have already defined information, I shall concentrate on defining the term "installed base" properly, after which we will relate it back to the concept of "installed base information".

The term installed base is commonly defined as the amount of products of a specific type, currently in use (Oliva & Kallenberg 2003; Brochers & Karandikar 2006). Ala-Risku (2009) defines installed base as the "set of individual pieces of equipment" currently in use. In the field-service context we shall adopt Ala-Risku's definition, as the heterogenic nature of customer inputs reduces the value of grouping equipment by type in favor of stressing the individual nature of the equipment.

However, to add a little meat around the bone, we shall examine the semantics of the term "installed base". The definition of "base", according to the Oxford dictionary[35], is "a

[35] Retrieved 28.9.2012

conceptual structure or entity on which something draws or depends". This entity can be a group of actors (such as a customer base) or, as in our case, a group of capital goods or complex systems or equipment. The word "installed" effectively excludes equipment which are still in production, delivery or installation, or equipment which has been decommissioned, limiting the term to equipment which are currently in use or in operational condition.

This means that we can rewrite the term "installed base" as "a group of equipment in operation on which something draws or depends". It seems as if there is a need to define who or what this "something" is. In the after sales context, I propose that four different perspectives on what this "something" could be will cover the range of relevant "something's" that draw or depend on the installed base, and consequently have an interest in information on it.

When we look at the lifecycle of any given equipment we can easily uncover the first three relevant perspectives, and for information gathering and utilization purposes, a fourth view becomes relevant:

- **The manufacturer perspective**, which defines installed base as equipment that have been delivered by the focal manufacturer (or delivered base): Interest in installed base information lies in R&D, warranty and sales, etc. (Ala-Risku 2009).
- **The service provider perspective**, which defines installed base as all equipment which are currently under contract with the service provider. Interest in installed base information lies in resource planning, supply chain management, routing etc. (Ala-Risku 2009).
- **The customer perspective**, which defines installed base as the set of equipment that is being used by the customer in his or her value creation. Interest in installed base information lies in asset management and long-term financial planning, etc. (British Standards Institution (BSI) 2008).
- **The equipment perspective**, which defines installed base as equipment of the same kind, type or function. Explicitly taking this view on the installed base could be for example regulatory industrial or governmental organizations or insurance companies, as certain elements of information can be expected to be similar between instances in this view, the most important function of the equipment perspective is that it forms a meaningful basis for aggregation within the other perspectives.

In short we can conclude that installed base information encompasses any information that is directly relatable to the installed base individual viewed from one of the perspectives mentioned above. This definition is well in line with Ala-Risku's (2009) findings, where distinct types of installed base information emerged from the field-service business contexts he examined:

- **Installed base item data** that relates to the installed items – their properties and their condition.
- **Installed base location data** that relates to the position in the customer process that an item can occupy.

- **Installed base event data** that relates to incidents involving the items and locations as well as describes interventions performed.

One could easily see that the item data is likely to reside with the manufacturer, the event data is likely to reside with the service provider and the location data is likely to reside with the customer. Further, as effective service provisioning in field services draws upon all three types of data, the challenge is how to make the data available where it is needed. Here the servitized manufacturers have an advantage, as the manufacturing and service provisioning happens within the same firm. With time, the knowledge of customers' operations will also accumulate, fusing the three perspectives and their respective data types into a fairly sustainable competitive advantage (Cohen et al. 2006). This of course provided that the flow of information is facilitated in a way which promotes its usage (Galbraith 1974).

Related to the five constructs in the literature framework, this subsection is concerned with customer inputs, which have been described as defining for services (Sampson & Froehle 2006). One input is, what was earlier described as the foundation for the business relationship, namely the capital good (or instance of installed base). The capital good is one of the central inputs being transformed during the actions. Further, installed base information is in a key role when striving for service operations excellence through improving decision-making and learning.

3.3 Summary of the reviewed literature

Before moving on to the case description, where the empirical context is described in detail, I will sum up the main points of this literature review, which will then be put into practice in section 5 and 6. First, in section 5, the empirical context will be analyzed through the literature framework described in subsection 3.1. Then, building on the analysis, design propositions (section 6) will be developed based on both the challenges identified by the literature framework and related theory presented in subsection 3.2. Finally, the effect of implementing the first design proposition will be analyzed, mainly relying on theory presented in subsection 3.2.2.

Value is a subjective measure based on the desirability of a change in the state of reality. When the change is a result of deliberate action, the change should be considered as an outcome of that action. Value is thus essentially a stakeholder's appraisal of a defined outcome. In industrial field services, the outcome is typically related to a change in the customer's assets or the customer's self, where information can be considered both as an asset, and as the customer's level of awareness. The value of outcomes will be evaluated on two dimensions by the customer, effectively separating what was done and how was it done.

Outcomes are the results of actions, which can be explicitly defined in processes or implicitly directed by experience. In a business environment all actions are deliberate; however, not all actions lead to the intended outcomes. Actions thus consist of an intentional manipulation of reality, which can be more explicitly defined as a transformation of inputs into outputs. In services the customer participates in the action, either through providing inputs, or performing some parts of the action himself. The variability introduced this way is one of the defining challenges of services. In industrial field services, the capital good is the essential customer input as it forms the basis for this business relationship. Preventive maintenance is explicitly concerned with ensuring appropriate predictability and availability of the capital good, however, the proactive nature of the activity complicates measurement of the outcome. Actions are always triggered by decisions; however, these triggers can be embedded through processes and IT-systems which effectively separate decision-making from action.

Decisions are always made based on the current perception of reality. For the decision-maker, reality consists of parts and pieces of information which are framed by the decision-maker in an attempt to make sense of the situation. Further, the decision-makers frames are accompanied by frame-specific policies and tools, which enable simple conclusions in complex situations. In industrial field services, installed base information is especially important considering efficient and effective service operations.

4 Case description

In the case description three primary data sources were used; process descriptions, interviews and a previous research report by Auramo et.al (2008) with focus on the field services of CaseCo. Further, secondary data sources, such as marketing material, annual reports and company web pages were used to some extent to enrich the data. The case description is a synthesis of the data analyzed, conveying a relevant view of the context and the focus of this thesis. We begin with a general description of the case company operations and history. After this we will discuss the business context characteristics, through covering the customers and the service base dynamics. We will then conclude with the CaseCo field services, complete with a more detailed look on the preventive maintenance process.

4.1 A general description of CaseCo

CaseCo is a large global manufacturer of capital goods operating in a machinery and solutions industry. CaseCo is considered a frontrunner in servitization, with roots in providing maintenance services for its products going back more than half a century. Today the CaseCo after sales service portfolio includes preventive and corrective maintenance, an emergency call-out service and equipment modernizations. Currently after sales services (including modernizations) account for more than half of CaseCo's revenues[36].

The capital goods provided by CaseCo are relatively high volume customizable solutions. The market for these solutions could be characterized as B2B, but the payer, chooser and the user are often three different parties with different priorities regarding preferred equipment characteristics. This consequently complicates service sales, as bundling of service agreements with new products is not straight forward. The capital good typically has a supporting role in customer operations, and in many cases equipment downtime is more of an annoyance than a catastrophe for the users.

In the service of these capital goods, CaseCo and a handful of other large players satisfy three quarters of the world demand. The entry barriers to the service markets are fairly low, which explains why there have been several CaseCo and competitor employees quitting their jobs in order to start their own small service business. Additionally, from a technological perspective the capital goods manufactured by different companies in this industry are quite similar, and accordingly CaseCo is willing and capable to service its competitors' products, and vice versa. As a result, in this highly competitive market, price is usually a prime criterion when choosing service provider.

The growing importance of the service business has resulted in a separation of new equipment business and service business. Today CaseCo has close to a million equipment individuals under maintenance contracts, typically lasting 1 to 5 years. The demand for maintenance services arises from, and is to a varying extent regulated by, national or industry legislation which is enacted primarily to ensure user safety. The reason for regulation is that the customer typically has limited competence for maintaining the capital

[36] According to financial statements 2011

good. Further the relative importance of maintenance services is stressed by the long theoretical[37] lifetime of the equipment, which can in some cases be up to a century.

For half a century CaseCo has had a strong emphasis on international growth through strategic alliances and acquisitions. During recent years CaseCo has sought to rationalize its global operations through harmonization of its processes worldwide combined with initiatives to improve field force efficiency. As a result, the company today displays impressive operations for providing field services to its customers globally. Many of the process improvements implemented during the rationalization were based on better utilization of installed base information, which is also the objective of this study.

4.2 The customers and the service base dynamics

The equipment installed at the customer site form the basis of the business relationship between CaseCo and its customers, and CaseCo strives to provide the highest possible technical service quality for all of its customers. The customers represent a broad spectrum of small to large businesses, with varying asset management capabilities. Further, most customers have in common that the equipment supplied and maintained by CaseCo has a supporting role in the customer operations, and is typically not operations critical. A customer has, depending on the customer size, from a single to hundreds of equipment individuals. Aside of being attractive business turnover-wise, the big customers also typically have several equipment individuals located in close proximity, which through reducing maintenance technician travel time increases maintenance resource productivity.

Figure 10 - Changes in the service base affecting preventive maintenance

The service base dynamics (see Figure 10, above) are relevant in this study because they have a direct effect on the demand and performance of preventive maintenance, and a direct effect on CaseCo turnover. When an equipment individual is commissioned it typically enters the service base of the equipment supplier. From a technical point of view there are differences in how preferable the incoming equipment are, as the service suppliers who also have a delivered base (OEMs) prefer to have as many of the delivered base items as possible included in the service base. The natural reason for this is that the OEMs have a better knowledge of the technical and reliability characteristics of equipment they have manufactured themselves, implying an enabler of more effective service provision (Vargo & Lusch 2004).

Reasons for exiting the service base are equipment decommissioning, or transfer to another supplier's service base. The typical contract timespan, reflected against the theoretical expected life of the equipment, adds up to a potentially high service base turnover. This is significant as the advantage of having self-manufactured equipment

[37] In practice, from a technical perspective, the equipment is effectively rebuilt a number of times

gradually deteriorates over time, especially if the equipment visits other service bases, as modernizations effectively turn the equipment into hybrids[38]. Further, the maintenance history is not recorded when the equipment is in another suppliers service base, thus the quality of the installed base information deteriorates, and the only currently available cure for this is customer retention.

4.3 The preventive maintenance process as a part of CaseCo field services

Once the equipment individual enters CaseCo's service base, it starts creating demand for different types of field services. The demand varies with respect to its predictability and financial impact, ranging from fairly predictable high impact modernizations to maintenance activities with varying predictability and impact on the customer. The maintenance activities can be further classified into three different categories based on their demand characteristics:

- Preventive maintenance – Service-provider triggered, predictable, low impact events, predetermined by a maintenance schedule. Mainly consisting of checks, inspections, adjustments and refills.
- Service repairs – Service-provider triggered events with varying predictability and impact. Typically involving replacing one or several parts.
- Call-outs – Customer-triggered, unpredictable events with varying impact, leading to corrective measures. Time-critical events as the primary function of the equipment is typically inhibited and/or the equipment usage might contain elements of inconveniency and even danger.

The maintenance field services are supported by an advanced logistics system for spare parts with central depots and proximity stocks. Further, the preventive maintenance activities are supported by installed base information enabled service route optimization. Remote monitoring solutions are also slowly gaining ground; however, due to low equipment criticality and relatively high service base turnover, a rapid growth in implementations is not expected at this time. To facilitate the need for information exchange and communication, that is inherent to field services, the technicians in most countries have a PDA-device (Personal Data Assistant) which enables work dispatching and back-reporting.

The preventive maintenance process builds on yearly maintenance cycles, defined for all equipment individuals. These cycles form a theoretically infinite work-cue, which the maintenance technicians tend to. This continuous process cycle is then occasionally interrupted by other types of maintenance activities (service repairs and call-outs). The high-level process logic of the preventive maintenance process is illustrated in Figure 11, page 40, and as such forms a foundation for process improvement (Jacka & Keller 2002).

[38] This is resulting in different part and assembly versions, and in case of having visited other service bases, different part and assembly OEMs.

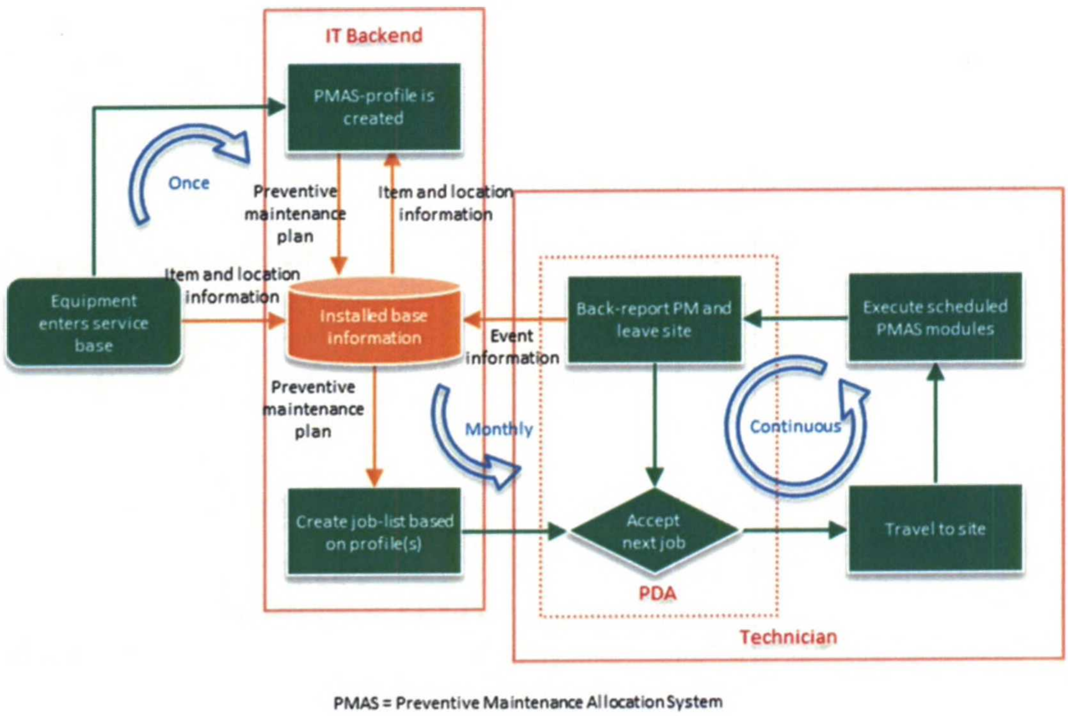

Figure 11 - Preventive maintenance process overview

As the equipment individual enters the service base, an individualized maintenance plan is created, based on item and location information, by the Preventive Maintenance Allocation System (PMAS). The preventive maintenance plan is then spread out over twelve months in a way which satisfies possible regulatory requirements and maintenance resource constraints. Once the plan has been created, monthly job-lists are generated based on the aggregated maintenance plans. Based on these job-lists, the maintenance technicians then perform jobs.

A preventive maintenance visit is initiated as the technician arrives at the site, after accepting the job and traveling to the customer site. Once there, the customer is contacted if needed, after which the technician proceeds to execute the designated preventive maintenance work. When the technician is done, he back-reports information about the job, and again contacts the customer if needed. After this the technician accepts and proceeds to the next job in the queue. When the technician has back-reported, the customer has access to some event data through a web-based customer portal.

Designating what preventive maintenance work should be performed on each visit is challenging with a heterogeneous service base, however, where there are differences, there are also similarities. A key to CaseCo success in the last decade has been a successful utilization of these similarities, whilst allowing the inherent diversity. This has been achieved through modularizing the preventive maintenance activities, according to different main components[39] which can be found in most equipment individuals. These work-modules form the basic building blocks of the equipment individual's preventive

[39] The technical basis for the modularization is motivated by demand for preventive maintenance arising from equipment reliability (Kelly 2006), and that the equipment reliability is determined by the reliability of its parts (Murthy et al. 2008).

maintenance plan (Figure 12, below). Further, the work-modules also form the basis for measuring maintenance resource efficiency.

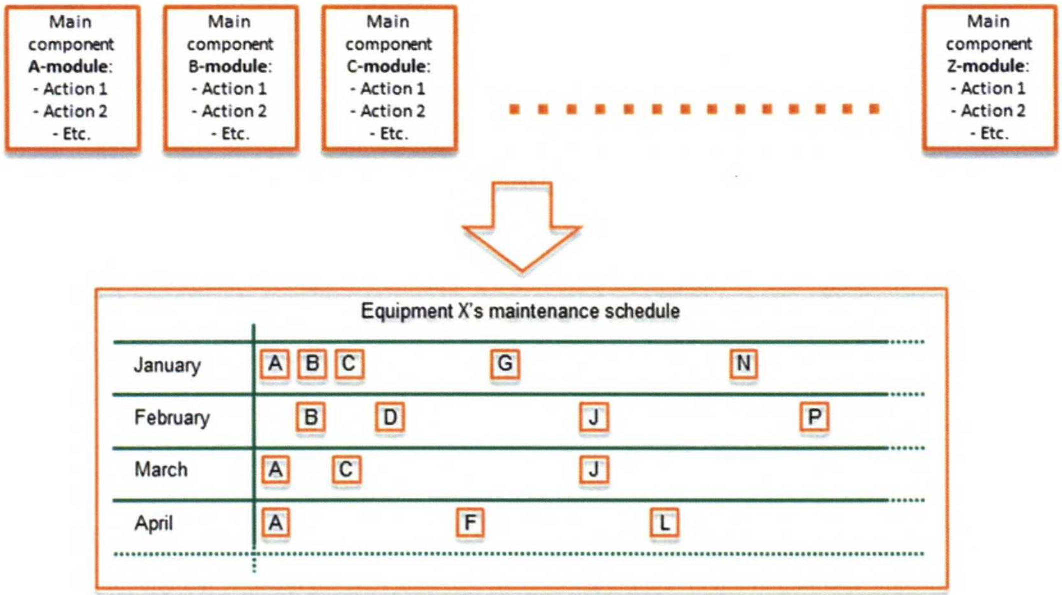

Figure 12 - Work-module structure of the preventive maintenance field service[40]

Before moving on to the analysis parts of the thesis, we will conclude with discussing the primary human decision-logic in the preventive maintenance process, namely the maintenance technician. Despite the process being clearly defined and communicated to the field personnel, the interpretation, experience and background of the service technician naturally affects to some extent how the detailed process is executed. This is dictated by practicality, as much of the information regarding work procedures, customer site and equipment specific information resides in the head of the maintenance technician.

[40] The actual number of main component work-modules has been disguised.

5 Analysis of the CaseCo preventive maintenance process

Studying a process for improving the utilization of information contains a slight contradiction. The source of this contradiction is that the process is basically a device that detaches the doing from the deciding, putting why something is done aside, only stating that it is done in this specific way. As the primary use of information is to reduce uncertainty in decision-making (Galbraith 1974), the contradiction is apparent; how can we attempt to improve decision-making in something which has no decisions.

The answer is; through uncovering the underlying implicit decision-making mechanisms (later referred to as decision logics) for analysis. We shall attempt to tie the information to the uncovered decision logics, determine what actions are taken in the domains of the decision logics, what their outcomes are and what value these outcomes have. When we've done this we can say that we understand the utilization of information, and can then attempt to improve it.

When improving the utilization of information, it is important not to consider the process itself as a static unchangeable thing. One of the presumptions is accordingly to question the whole process and the way through which it creates value. Such a process re-engineering approach (cf. Hammer & Champy 1993) however is impeded by the narrow focus of this study, as radical changes in the way the process is executed, will inevitably have consequences for other parts of the service delivery function. Additionally the process is very top level due to the global diversity, making it hard to improve through traditional process re-engineering approaches.

In this section the literature framework constructed in subsection 3.1 will be applied to the case context. In subsection 5.1 we will begin by analyzing the value elements, which form the customers' perception of value. In the following subsection 5.2, we will distinguish the outcomes which link the preventive maintenance (PM) actions to the value perceived by the customer. Then, in subsection 5.3, we will have a closer look on what actions preventive maintenance comprises of, and connect these to the presented outcomes.

In subsection 5.4 we analyze the decision logics which trigger the PM actions. Here we will analyze both explicit decision logics and uncover hidden, implicit decision logics. Then, in subsection 5.5, the currently available information will be presented, and at least partially tied to the decision logics presented in the preceding subsection. Finally, in subsection 5.6, the analysis will be summarized through the approach described in the concluding subsection 3.1.6 of the literature framework.

5.1 Value created by the CaseCo PM process

Value is always subjective, and there are as many views on value as there are stakeholders. The B2B customer looks at value from two perspectives. One perspective is the perspective of the customer's customer, who in most cases is the user. The other perspective is from the customer's shareholders, which have their own set of expectations on value-creation. From the supplier viewpoint value should rather be seen as waste reduction, as added value is typically an improvement in the way the supplier can use their resources to achieve their objectives.

As supplier value creation cannot be detached from customer value creation, we have a slight chicken and the egg dilemma. I will here assume the viewpoint that all supplier value, or rather waste reduction (current and potential) happens in the decision and action nodes of the literature framework. Thus, even if we could easily say that increasing the predictability and thus manageability of operations is clearly related to supplier value, the supplier's value is always realized while creating customer value. The same thing goes for better matching service provision to service demand (i.e. doing the right thing), where reduction of over- and under-maintenance is surely related to supplier value, provided there are no regulatory constraints.

Based on this reasoning, we will now go through the value elements from the customer perspective, and subsequently, supplier value will be implicitly uncovered in the following subsections (5.2 to 5.5). As one of the main objectives of this thesis is to explore waste reduction through improved information utilization, the design propositions in section 6 will have an emphasis on waste reduction, or, how to improve supplier value.

Equipment availability - The customer does not care for unexpected equipment breakdowns

Availability of equipment is naturally a high ranking value element. However, most customers do not see this value element in terms of availability, but rather the absence of unplanned repairs. With customers where the equipment plays a more critical role in operations, the term availability is more frequently used.

Financial predictability - The customer prefers knowing about bigger repairs well in advance

Basically this value element is quite similar to the first element of value, emphasizing that there is both a long-term and a short-term element to predictability. In the short-term the customer does not want any equipment breakdowns and in the long-term the customer wants to be aware of major repairs well in advance. Here predictability takes a more financial dimension, taking into account the asset management viewpoint. It is however hard to define or even fulfill this type of information needs beforehand. It is rather the typical case of; we would have liked to have information on this major repair two years ago in order to adapt our finances.

Regulatory compliance - The customer has to conform to rules and legislation

There are several possible regulations to the maintenance of the equipment in question. These rules and regulations vary from region to region, and are stipulated by national governments, international organizations and industry organizations. The rules typically regulate the yearly number of PM visits or the documentation of maintenance and accountability in case of accidents.

In the case of a predetermined number of PM visits, the legislation is usually lagging behind the performance of modern technology[41], making the number of visits unnecessarily high from a technical viewpoint (it is still good business, as long as you are getting paid for it

[41] Note that this is another example of an embedded decision logic where the time elapsed since the decision/stipulation reduces its validity, as reality is changed by technology

though). Additionally, the legislation and regulation can be expected to affect customer behavior, even after it has been removed as it takes time for the customer mindset to change.

Service visibility - Customers need to be able to verify what they are paying for

The inherent problem with preventive maintenance is that the better, or the more successful the service is, the more it looks like no service is being provided at all. In some cultures the customer has a need to verify that the service has been delivered. This translates to a need of making the preventive maintenance visible to the customer. The reluctance of letting go of the previously mentioned 12 month (yearly) mentality might also be partly attributable to this need.

Customer involvement – The level of preferred interaction varies

The degree to which a customer wants to be involved in the service process varies from customer to customer. In one end there is the typical cost-aware short-sighted small customer, which prefers to be aware of all repairs and incurred costs, and needs to have the final say in all expenses. In the other end there is the professional service outsourcer who prefers having as little as possible to do with the service delivery, in order to be able to concentrate on their core areas.

Customer awareness – The customer prefers knowing everything he considers relevant about the equipment

Being a combination of the financial predictability and service visibility value elements, customer awareness highlights the communication channels through which the service provider and customer interact. Being at the frontend of the service operations, the maintenance technician is an important communication channel with the customer (Johnston & Clark 2008; Turunen & Toivonen 2011). Thus, the maintenance technician sometimes contacts the customer in connection with the preventive maintenance visits, and is able to answer possible customer questions.

5.2 Outcomes of the CaseCo PM process

The outcomes are the results of the actions and the change in the state of reality against which value is perceived. By disconnecting action from value, outcomes also introduce the possibility of making seemingly correct decisions, perform the action perfectly, but still fail to produce value. Inversely outcomes also enable situations where the retrospectively seen wrong decision is made, or the action is performed wrongly, but value is still generated.

The foremost purpose of outcomes is that by serving as the link between action and value, this is the place where you measure if you are doing the right things (vs. doing things right). Thus, here when considering outcomes, we will explore which changes (in the state of reality) really are the outcomes of the PM actions. We also consider which factors affect the measurement of the outcome, and how it is measured today.

Equipment condition confirmed and wear-failures postponed

Preventive maintenance is preoccupied solely with expected failures, as the role of preventive maintenance is twofold. On one hand preventive maintenance is to detect the impending failures, which translates to detecting parts that have irreversibly entered the wear-out phase. On the other hand, preventive maintenance is to postpone the entry to the wear out phase through for example cleaning and lubrication.

These two elements; detecting failing parts before they fail, and postponing the initiation of the failure mechanisms, are the main outcomes of the preventive maintenance action. They are however not directly suitable for performance measurement, as the first has a certain degree of subjectivity attached to it and the second is not easily quantifiable. The solution in CaseCo has been to monitor the contingent variable of unexpected failures, or call-outs.

On top of being directly connected to customer value through preventing unexpected equipment breakdowns, measuring the call-outs is important for the supplier operations, as it is effectively a measure for the predictability of the service operations. The predictability dictates the extent to which operations can be pre-planned, and consequently the extent to which the service operations can be optimized. From the preventive maintenance perspective, doing more preventive work can be assumed to reduce the number of expected faults actually realizing, thus improving service operations manageability, which is desirable.

The crux of the matter is that although increasing preventive maintenance reduces the occurrence of unplanned maintenance visits, the cost of increasing preventive maintenance has to be weighed against the benefit of the increased predictability. The balance of preventive and corrective maintenance is not fully captured by the call-out rate, however if the desired call-out rate is given, an optimal amount of preventive maintenance exists on the aggregate level. A positive or negative deviation from this optimal amount is respectively termed over- and under-maintenance.

The common suspicion among the interviewees was that CaseCo is currently over-maintaining its equipment. It was also noted that although the call-out rate gives a general indication of the situation, the measurement of over-maintenance is far from straight forward. This is further complicated by the fact that the value deriving from this outcome is postponed, which means that any changes in the actions leading to this outcome need to be evaluated over time.

Functionality confirmed – assuring and restoring end-user experience, safety and convenience

The preventive maintenance also tends to the user experience of the final equipment user. The actions leading to this outcome typically consist of tolerance checks and adjustments which do not affect the primary function of the equipment, but rather effect convenience of usage. There is no matching value element for this outcome as it is indirectly linked through equipment availability to the end user. However, if the threshold to report the inconvenience is crossed, the customer gets the information from the user and reports it to the supplier as a fault, which is equivalent to an unexpected failure and consequently a call-out.

A preventive maintenance visit - in case of contractual requirements

As previously mentioned, in some regions it is custom to specify a required number of visits in the maintenance contract, due to legislative or regulatory reasons. From the CaseCo perspective these contracts are just as good business as the unregulated contracts, but from the customer perspective they are likely to contain a considerable amount of waste, as they typically bound the service provider to over-maintaining the equipment. As travel time has a considerable impact on resource productivity in field-services, there is a strong incentive to minimize the number of visits. The required number of visits, from a technical point of view, in theory defines the lower limit for the number of visits. In practice however, this limit is very difficult to define.

Service visibility and transparency

As previously mentioned, service visibility is important for some customers. In these cases the technician should attempt to contact the customer, as an important outcome of the preventive maintenance process is service visibility and transparency through customer communication. Service visibility and transparency is also partly facilitated by the WebPortal which allows the customer to access some event data which is recorded as the technician back-reports a maintenance visit.

5.3 Actions in the CaseCo PM process

Actions are the instances of applied resources which cause a change in the state of the object of action (the customer input being transformed). Alternatively actions can produce information about the state of the object of action. Typically actions produce both of these and additionally information about the change process such as resource performance. Next we will go through what actions are performed in connection to the preventive maintenance process.

Contacting the customer, if applicable

This action is connected to the service visibility outcome, and its primary purpose is to inform the customer of work initiation or completion, and discuss its extent and consequences to the customer operations. Aside from raising the customer's level of awareness, this action might also produce important information regarding the execution of subsequent action, such as customer preferences on the order of the work to accommodate customer operations. Further in some cases this action is a prerequisite for the following ones as the concrete outcome of the action can be that the maintenance technician is granted access to the customer's equipment.

Performing designated work-modules - a combination of inspections, checks, adjustments, cleaning and lubricating

As described in subsection 4.3, the PM actions are grouped in work-modules based on which the individual PM plan and subsequently PM visits are built. Each of these work-modules contains a set of actions which are to be performed on the main component, consisting of inspections, checks, adjustments, cleaning, lubrication and other typical preventive maintenance actions (cf. Kelly 2006).

In one of the studied work-modules there were some granularity problems. These originated from the fact that the work-module actually contained several instances of the main-component, grouped in one work-module. While the grouped main-components are in most cases technically identical, they were subjected to different levels of usage intensity and different operational environments. This implies differences in the reliability of the main components and consequently differences in the demand for preventive maintenance (Murthy et al. 2008; Kelly 2006).

Back-reporting

Back-reporting is done through the maintenance technicians PDA device. The back-reported information is then used in preventive maintenance resource performance monitoring, and in several processes outside the preventive maintenance process.

5.4 Decisions in the CaseCo PM process

As decisions are always bound to a specific point in time, the decisions themselves are hard to detach from the context for analysis. However, the decision-makers are easier to detach, which means that we should rather be talking about decision logics than of decisions. In the preventive maintenance process there are several different decision logics in play, of which the two most important considering the outcomes of the process, are the maintenance technician and the Preventive Maintenance Allocation System (PMAS). Of these two decision logics, the former is adaptive (explicit and active), while three latter is static (implicit, embedded and passive) and detached from the current state of reality.

Additionally the supervisor has a small role in the preventive maintenance process, as he is responsible for monitoring the performance of the maintenance technician. Further the execution of the process and the preventive maintenance work is guided by documentation which should be considered as passive decision making logics. However as mentioned earlier, partly due to the heterogeneity of the service base, the maintenance technician does (or can) not necessarily rely that much on the documentation.

The maintenance technician decision logic

The maintenance technician represents the decision logic that gets closest to the equipment individual. This means that the technician has access to installed base information which resides with the equipment. The technician might also remember event data related to possible earlier jobs at the equipment. Based on these sources of information, the technician can make adaptive on-site decisions, which is handy especially in problem solving situations. Provided the technician has a picture of the knowledge base of others, he can also utilize their decision logic by calling them.

While the technician will learn and adjust his way of working according to the results he observes, the learning ability of the technician's decision logic can also cause waste. A seed for this is sown when the technician develops habits, routines, or creates rules of thumb based on the circumstances at hand. Over time these circumstances might change and the technician ends up making decisions based on outdated assumptions.

A problem brought up by some interviewees concerned the underutilization of the technicians' decision logic, especially in matters concerning the preventive maintenance plan. As the PM plan is created utilizing item and location information, the technician is in prime position to verify this information (cf. Turunen & Toivonen 2011). However, it is currently difficult for the technician to verify what information the preventive maintenance plan is based on. Further the maintenance technician might, at least in the long run, have a gut feeling of, if an equipment individual is currently being over- or under maintained.

The Preventive Maintenance Allocation System (PMAS) decision logic

Where the maintenance technician is the primary decision logic when it comes to how the preventive maintenance activities are carried out in practice. The PMAS is the primary decision logic when it comes to when and how often the preventive maintenance activities are done. Aside of the inherent reliability, which arises from equipment design and utilized technologies, Murthy et al. adds that the reliability field performance of an equipment individual is determined by usage intensity[42], usage mode[43] and operational environment[44]. As the usage mode is somewhat given for this type of equipment, the PMAS chooses a suitable yearly maintenance plan based on the equipment (technical) type, usage intensity and operational environment specified for the equipment. It then allocates the work in such a way that regulatory requirements and maintenance resource constraints are satisfied.

The tendency of equipment turning into hybrids over time complicates the determination of the equipment type variable. In practice this has created the need for a universally applicable equipment type, which produces a generic maintenance plan. The usage intensity is typically estimated, and the operational environment is subjectively evaluated when the plan is created. These three characteristics (Murthy et al. 2008) determine (Kelly 2006) the number of work-modules allocated to the equipment, thus making up the preventive maintenance plan. In cases where the equipment is critical to customer operations, the maintenance plan variables are adjusted to create a satisfactory, customized plan.

The PMAS is not concerned with how the allocated maintenance work is executed; however, the work-modules used in building the maintenance programs also enable maintenance resource performance monitoring. The event-data created by the maintenance technicians is analyzed, in a way which reveals both poor performance and better ways of doing things, effectively introducing a learning mechanism into the preventive maintenance process on the part of how preventive maintenance actions are performed.

In contrast with the maintenance resource performance, the PMAS determines the maintenance schedule once, and then it remains unchanged with no one questioning it, as the maintenance technicians do not always know what information the maintenance plan is based on. In practice, only cases of severe under-maintenance will cause a revision of the underlying information, as they are easier to detect than over-maintenance. This means

[42] Which determines the load – electrical, mechanical, thermal, chemical – on the unit
[43] Whether used continuously or intermittently
[44] e.g., temperature, humidity, vibration and pollution

that on the part of how often preventive maintenance actions are performed, there is very little learning.

5.5 Information in the CaseCo PM process

CaseCo has a significant amount of binary installed base information, in all Ala-Risku's categories (2009); item, location and event. There are, however, regional variations in information availability and some information quality issues with the CaseCo IBI, which ultimately have an effect on the success of the PM process. The quality issues can be described through the concepts of information granularity (the hierarchical level describing the state of reality) and frequency (the time-intervals at which the state of reality is observed), which were elaborated in subsection 3.1.1. Further, the requirement that information needs to be specifiable was emphasized through problems with the subjective evaluation of the operational environment.

Concerning information granularity, the interviewees saw where more accurate technical information could be utilized; however, the collectability of this information was questioned in some cases, given the diversity of certain main component types, hampered by the difficulty to identify the type. Further, the granularity of the usage intensity information was questioned by one interviewee, suspecting that more accurate information would enable better maintenance plans.

Information frequency was mentioned in connection to the usage intensity variable, which often has to be estimated at service base entry, and then there is a certain lag before it can be confirmed. Related to this, the implementation of remote monitoring is typically driven by the desire to increase the information frequency. CaseCo has remote monitoring in place in some newer, CaseCo manufactured equipment. However, at this stage the utilization of remote monitoring information is in its infancy, while it is expected to improve the predictability of operations in the future.

The operational environment information was mentioned by several interviewees as a source for information inaccuracies. Despite that the determination of the operational environment information is backed up by instructions, the subjective dimension attached to its evaluation, makes it susceptible to errors. Further, it was suspected that these inaccuracies were sometimes intentional in cases where the system created maintenance plan was considered to light.

On a more general note, information accuracy problems seemed to emerge more frequently in situations where the information was collected by someone who does not use it directly or whom it does not affect. Other problematic situations in that sense are when the information cannot be confirmed by the one using it, or if the information is unavailable to someone who could confirm it. Further, it was found that the information is more likely to be incomplete in situations where the information is not utilized, or the (potential) collector does not understand how the collected information contributes to his personal or company success.

5.6 Concluding remarks on the CaseCo PM process

The CaseCo preventive maintenance process expressed in the terms of the literature framework (subsection 3.1) is depicted in Figure 13, on page 50 (according to principles described in subsection 3.1.6). In the illustration, the decision-making logic is represented as a node, but also as an area of influence, indicating where the information resides. Through overlaps in these areas we can further see which decision-making logics share, not only certain nodes of information, but also action, outcomes and value.

The special characteristics of the context emerge from Figure 13, below, as there is no overlap between the user- and the service technician decision-logics. While the value elements are identified around the asset management decision-logic, it is obvious that these are secondary from the point-of view of the user, who is only concerned that the equipment is providing the value it is intended to provide in a way which satisfies the user. Connecting the user decision logic to the service provider, could provide a clearer insight into what the user values, and thus, what the actual customer will also subsequently appreciate.

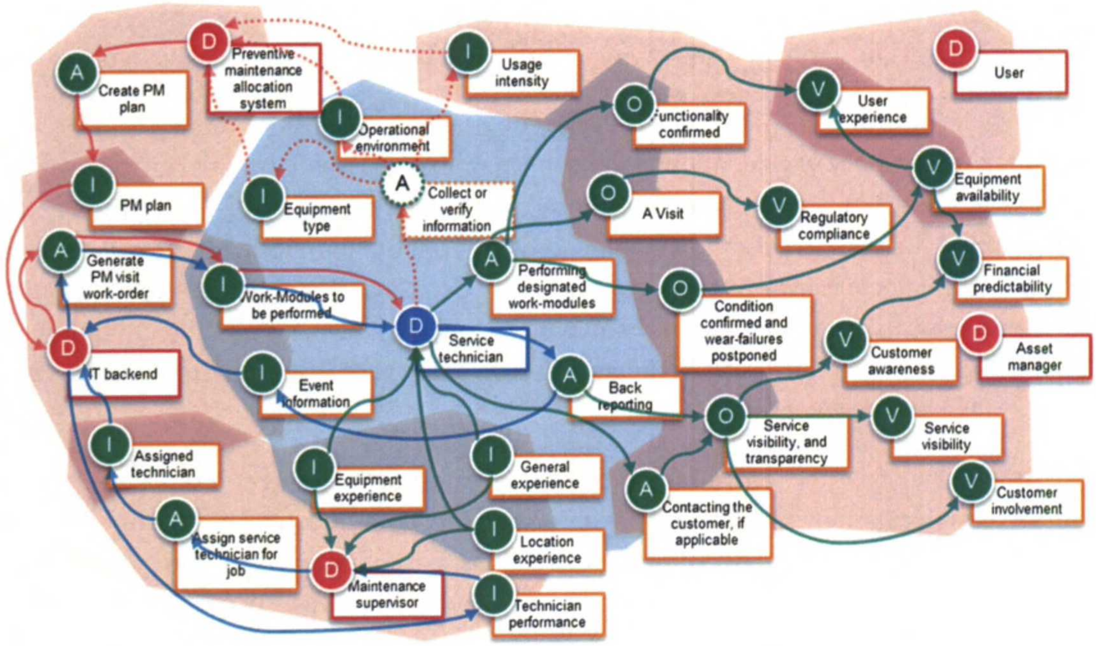

Figure 13 - How information translates to value in the CaseCo preventive maintenance process

Despite the actual asset missing in the picture, we can see the two essential feedback-loops of the process:

- The active feedback-loop (forming an eight through the blue arrows) where the technician's performance is being evaluated. Starting from the technician back-reporting, creating event data. Based on the processed event data the maintenance supervisor can evaluate the maintenance resource performance and adjust his resource allocation accordingly. Based on this the supervisor can also identify training needs etc.

- The (inactive) feedback-loop[45] (forming a loop through the red arrows[46]) where the equipment type, usage intensity and operational environment are recorded when the equipment enters the service base, based on which the preventive maintenance plan is constructed by the PMAS-system.

From the analysis we can extract a number of current challenges, all either directly or indirectly relating to how the PMAS selects a suitable maintenance plan. The performance measures in place for the actual execution of maintenance seem to be well in place. Essentially CaseCo is currently well off ensuring that <u>things are done right</u>; while there are certain doubts when it comes to continuously ensuring that <u>the right things are done</u>.

In this section, supported by section 4 and subsection 3.2, we have explored and answered RQ1: **How is installed base information currently utilized in preventive maintenance field services, both directly and indirectly?** However, the emphasis has clearly been on direct utilization. Also, in this section, supported by section 4 and theory from subsections 3.1 and 3.2, we have explored and answered RQ2: **How does installed base information utilized in a preventive maintenance field service context translate into value?** Further, we have reached the objective of the thesis by linking installed base information to value in the chosen context. A short and concise answer to each research questions is presented below:

RQ1: **How is installed base information currently utilized in preventive maintenance field services, both directly and indirectly?**

Installed base information, mainly item and location information, is directly utilized in individualization of maintenance plans. Further, event data is utilized in performance measurement of the preventive maintenance resources, or the maintenance technicians. Installed base information, item and location information, is indirectly used in preventive maintenance through the spare part supply-chain and technician route planning processes. While this sums up the primary uses of binary, hard installed base information, it was found that the maintenance technician typically have valuable "soft" installed base information, such as site access details and equipment history.

The initial assumptions (see section 2) stated that installed base information was expected to be used "to a limited extent". The evidence does however suggest that multiple types of installed base information are used quite extensively, however, there were also several cases of unused information and potential uses with no information. The other part of the assumption was however spot on, considering not only utilization of the existing information, but also the lack of interest in collecting information when the benefits could not be seen.

RQ2: **How does installed base information utilized in a preventive maintenance field service context translate into value?**

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[45] Technically there is no such thing as a one-time feedback-loop, but as I am going to suggest that the loop should be continuous, I took the liberty of calling it an inactive feedback-loop.
[46] Design proposition 2, which is presented in subsection 6.1 is included to complete the loop

Information translates into value through being used in informed decisions, which trigger and define actions, which lead to valued outcomes. Item and location information can be connected to performing the appropriate and necessary preventive maintenance actions, leading to desired equipment availability or failure-rate. Event data can be connected to waste reduction through enabling control of maintenance resource efficiency. Event data was also transformed to customer value through service- and equipment-awareness and proof of regulatory compliance.

The initial assumptions on this point were quite vague, only stating that a lack of holistic perception on the transformation was expected. While this is hard, and not even that valuable to confirm, it seems as if our cognitive limitations drive us to evaluate the holistic picture based on its bits and pieces. This being said, the impression given by the interviews is that the interviewees were able to consider the translation into value, or at least outcomes, through describing the holistic picture as a sum of causal chains. This is probably also why it is fairly hard to compare the benefits of having two different types of information.

In the next section, I will present the challenges and elaborate on their underlying mechanisms to the extent that it has not been done in the analysis yet. Further, recommendations on how these challenges should be addressed are given in the form of design propositions. The effects of implementing these design propositions will also be discussed. In section 7, I will then present a detailed analysis of design proposition 1.

6 Identified challenges and how to address those

In this section I will present the challenges detected in the analysis of the preventive maintenance process. All of these challenges are directly or indirectly related to how the preventive maintenance work is allocated to equipment individuals, and most are directly related to how the maintenance plan is constructed by the PMAS. Consequently, a common outcome for most of the presented design propositions is a reduction of potential under- and over-maintenance. This section is structured according to the detected challenges (6.1 - 6.4):

- Evaluation of the selected preventive maintenance plan is not an active part of the process
- Possibilities for optimizing the preventive maintenance plan are limited
- Insufficient information and action granularity causes waste
- The preventive maintenance service operations are mainly push-driven

The underlying mechanisms of each of these challenges are recapped, after which design propositions are developed, their rationale explained and outcomes of their implementation discussed. Subsection 6.5 is devoted to a short discussion on broader implications of the proposed design propositions, complete with closing remarks on this section.

In arriving at these design propositions, effectuation was the primary approach. The use of causation seemed a bit challenging as the market for these services are quite mature and competitive. There is however some improvement potential when we look at the value elements of customer awareness and financial predictability, also supported by these design propositions. Before moving on to the design propositions I wish to remind the reader that a strict focus was kept on how the preventive maintenance process could be improved. Thus, some of the design propositions have potential positive spillover effects considering other processes, but these are not elaborated.

6.1 Evaluation of the selected preventive maintenance plan is not an active part of the process

After the preventive maintenance plan has been created, it is "locked", as the plan is not questioned or challenged, with the exception of radical cases of under-maintenance. When the plan is questioned, it is only the information on which the plan is based, which is checked. In practice this is only a check of the underlying assumptions, implying only partial learning as the decision logic itself is not evaluated.

Another observation was that the PMAS does not use event data that forms the basis for the learning mechanism in the maintenance resource performance evaluation. This was seen as a good starting-point for introducing a learning mechanism into the PMAS, through effectuation, backed up by the interviewees' suspicions that equipment is currently over-maintained. Thus, the first design proposition (DP1) is formulated:

DP1: Enable maintenance plan learning through utilizing event-data

The performance of the preventive maintenance resources is measured through utilizing quite rudimentary event data. This simple information is then turned to useful measures through information processing. This shows that it might be possible to establish a learning mechanism in to the PMAS using rudimentary information, despite the event data collected by CaseCo being quite rich.

From a theoretical perspective, the suitable preventive maintenance plan is determined by two concepts (see subsections 3.2.2 and 5.2), the detectability of impending failures, and the postponement of initiating wear-out failures. Thus, any measurement of preventive maintenance plan appropriateness should be based on these two components. Both of these components are connected to the preventive maintenance intervals, in the sense that they both affect the failure-rate as a function of time elapsed since the last preventive maintenance action. When the evaluation of these two components is an active part of the process, we can talk about a learning mechanism. Next we will look into how the collected event data could support such a learning mechanism.

Through reference data, the event data can typically be connected to other types of data (Ala-Risku 2009). In CaseCo, the event data can be traced to the main component level, in most maintenance events. Further, the event types per se give a hint of what type of maintenance action and situation is in question. Even richer data concerning the events was available in the data set provided by CaseCo; however, despite being expected to add value to the analysis, the data was not utilized due to computational limitations and some data quality concerns.

As both failure detectability and postponement of wear-out failures is expressed in the failure-rate as a function of time elapsed since the last preventive maintenance action, the need for data is all but extensive. To set up this type of measure, we need to know the event type (essentially PM or call-out), the object of the service action (work-module of failed main component) and a timestamp. Then we have to make one important assumption; when the service technician performs the preventive maintenance, he leaves the site confident that the equipment will survive without failures to the next preventive maintenance visit. When the information is aggregated and the assumption holds true, it results in a measure which facilitates maintenance plan learning through enabling fine-tuning of the preventive maintenance intervals (for conceptual illustration, see Figure 19, page 68), effectively reducing over- and under-maintenance. Considering implementation however, the next challenge, presented in subsection 6.2, has to be addressed first.

While the *Call-out rate distribution over time since last preventive maintenance visit*-measure, lined out above, allows tuning of the aggregate level intervals, it does not uncover over- and under-maintenance on equipment instance level. For this we can use a coarser measure, which can (and should) be applied alongside the one mentioned above, and which is compatible with the way the maintenance plan is currently built. We begin by making the seemingly safe assumption; that the demand for preventive maintenance correlates with the failure-rate. If this assumption has even the slightest ounce of truth to it, reallocating preventive maintenance resources from equipment with low average failure-rates to equipment with high average failure-rates should on average lead to better results in terms of the average failure-rate.

In practice we would arrange the equipment according to average failure-rate (in some appropriate timespan), which is derived through event type and timestamp. We then group the equipment according to how many preventive maintenance visits they are currently subjected to, derived from the current maintenance plans. Then, assuming that the average failure-rate is not continuous between the groups we would move a designated number of equipment (say 5-10%), with exceptionally high or low failure-rates, from both ends of the spectrum to the neighboring groups, respectively (for conceptual illustration, see Figure 26, page 73). This reallocation would facilitate maintenance plan learning through improved matching of preventive maintenance demand and supply, effectively reducing over- and under-maintenance.

The second measure, which we shall call *Service base failure-rate distribution*, would effectively override the PMAS decision-logic, through complementing it with an experience based service provision-logic. In case this sounds too radical, the override could (and should) be preceded with a request to verify the information on which the PMAS generated preventive maintenance plan is based. Being based on a problem recognized by the interviewees, this would direct information gathering and verification efforts to where it is likely most needed. Verification would then either confirm the need to deviate from the PMAS generated maintenance plan, or spark the generation of a new plan. For this to work however, we have to make the second design proposition (DP2):

> ***DP2: Make information available also where it can be verified, not only where it is used***

Depending on how the information is aggregated through the *Service base failure-rate distribution*-measure, the information verification efforts could be stated as very specific tasks, such as "confirm operational environment" or "verify main component A type". Especially in the case of main component, the information verification process could then be rationalized so that the verification request is communicated to the technician through the PDA, as he is performing preventive maintenance on the equipment in question, and is scheduled to service the main component in question. Naturally this implies that also the existing information needs to be communicated (preferably via the PDA) to the technician, but whether the information should be available and modifiable at all times is (at least currently) questionable, due to ambiguity issues.

Based on how we define the exceptionally high or low failure-rate, the selective information verification would look something like Figure 14[47], on page 56. If implemented so that the request to verify information is presented when the technician is working at the source of the information, the additional resource requirements of information collection or verification would be minimal. Implementation of this design proposition can be expected to result in increased installed base information quality.

[47] This keeping in mind the special actions with the radical cases of under-maintenance

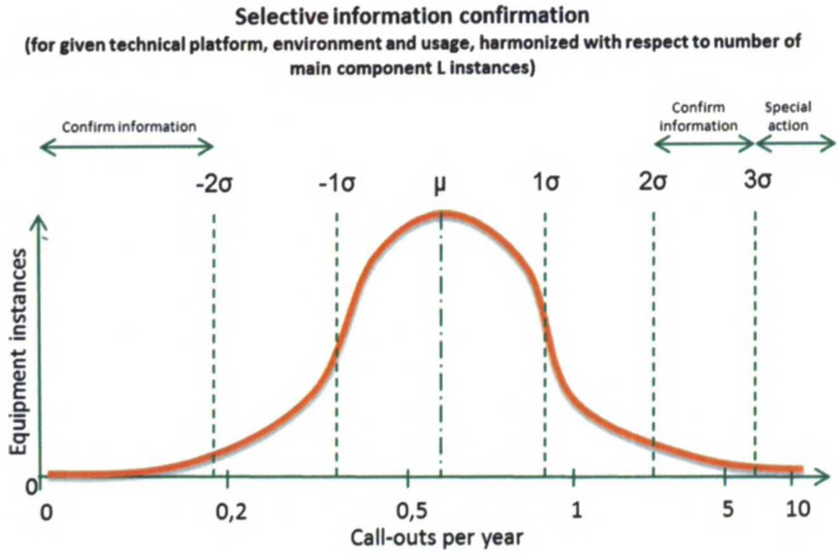

Figure 14 - Ranges for selective information confirmation

From an information flow point of view, increasing installed base information quality in this case means making sure that the correct information is available where the decisions are made. An inverse approach to this is making the decisions where the correct information is available. This forms the basis for our third design proposition (DP3):

> ***DP3: Introduce an explicit modification mechanism for the maintenance plan in order to harness the experience of the field personnel, and subject tweaking to control***

There are several reasons to why maintenance plans may be based on incorrect information. Sometimes the incorrect information is caused by failed data collection, failed interpretation or incorrect estimation. However, in some cases it is deliberate; done in order to create a customized maintenance plan in case of exceptional equipment criticality or perceived inadequacy of the proposed maintenance plan.

As the maintenance technician might, at least in the long run, have a gut feeling of, if an equipment individual is currently being over- or under maintained, deliberate preventive maintenance plan modification by the technician should be made possible. This would be a second way of overriding the PMAS decision-logic, through complementing it with the technician decision-logic. However, as this is already basically happening today, the challenge, and the crux of this design proposition is rather to make the modification an explicit part of the process, and subject it to performance measurement. As a consequence of this, the performance of the modification has to be communicated to the technician decision-logic, in order for learning to happen there.

In practice the maintenance plan could be made lighter or heavier than the PMAS proposed plan, perhaps with a certain percentage affecting the maintenance intervals and allocated work-modules (provided that the next challenge, presented in subsection 6.2 is addressed). The modified maintenance plan would then be flagged for follow-up, where the performance of the plan against the originally proposed plan is evaluated using the measures described in *DP1: Enable maintenance plan learning through utilizing event-data.*

A successful modification (in either direction) should off course be awarded, while unsuccessful modifications should lead to corrective measures on the maintenance plan and recurrent unsuccessful modifications should lead to corrective measures on their creator.

While the issue of incentives in this case needs to be further studied, this empowering mechanism should have a general positive effect on the technician motivation and moral. On average, implementation of this design proposition could be expected to reduce over- and under-maintenance and perhaps also decrease workforce turnover.

6.2 Possibilities for optimizing the preventive maintenance plan are limited

Due to the twelve month planning cycle that dominates the industry, all the preventive maintenance schedules are currently constructed as 12 month cycles (with the granularity of a month), which means that the number of work-modules executed per year has to be an integer. Converted to maintenance intervals, the applicable intervals are thus 12, 6, 4, 3, 2, and 1 month. This restricts the possibilities for fine tuning the maintenance plan as suggested in *DP1: Enable maintenance plan learning through utilizing event-data*. Further, this system limitation was suspected to cause some over-maintenance, however, as over-maintenance is hard to quantify, it is equally hard to weigh it against the benefits of the current system.

We can assume that the "number of visits per year"-type restrictions, especially technically motivated restrictions, are difficult to influence. However, we can also assume that a slow change in regulation, followed by a change in mindset is happening, driven by the increasing reliability of the technology involved. As a reaction to this trend, and as a complement to the first measurement method in *DP1: Enable maintenance plan learning through utilizing event-data*, I propose the following design proposition (DP4):

DP4: Move from a yearly service provision design basis to a service provision interval design basis

Whether the maintenance intervals should be defined through elapsed time was also questioned, as usage intensity was suspected to be a more relevant figure. This is a just concern, as in most cases where the equipment is operated in a controlled (and favorable) environment, time as an independent factor could be expected to have little effect on the deterioration of the equipment condition, whereas the actual usage is a direct cause of mechanical wear and tear (Kelly 2006). The rates of deterioration could however be considered as a distribution, to which time presents a satisfactory approximation, even though it be through estimated usage per time.

The growth of remote monitoring implementations suggests that up to date usage figures will be more readily available in the future. Based on this I propose that the defining mechanism for the preventive maintenance intervals should be left open to modification, or dual inputs, despite the apparent need to translate the intervals to time as long as real-time usage figures are unavailable.

Increasing the flexibility in preventive maintenance work allocation is a prerequisite for the fine tuning-mechanism proposed in *DP1: Enable maintenance plan learning through utilizing event-data.* Together these design propositions enable aggregate reduction of over- and under-maintenance.

6.3 Insufficient information and action granularity causes waste

Information granularity refers to different levels of the hierarchy of information (see Table 4, page 20), where a higher level is an aggregation or combination of lower level information. The granularity of information is thus basically a measure of the richness of detail. The optimal level of granularity is dependent on the decision-makers information processing capacity, and the relationship between the resources spent collecting the information compared with the resources saved through utilizing the information. The concept of granularity can further be extended to action through assuming a traditional process view, where the level to which tasks are process instance specific, determines the granularity.

In our analysis we identified two cases of insufficient granularity. The first concerns the operational environment information, which was found problematic due to ambiguity in the way it is interpreted when collected. The second concerns the main component work-module, which housed several similar main component instances, subjected to different usage intensities and operational environments, resulting in different needs for preventive maintenance. In the following two design propositions (DP5 and DP6), we will explore how the granularity should be increased, starting with the operational environment information:

DP5: Increase the granularity of the operational environment information to reduce problems caused by subjectivity

Based on the interviewees' perception of significant operational environment characteristics, I propose that the operational environment be expressed through four variables. These four variables would all be recorded in binary form, and recorded in a way which leaves little room for ambiguity. Subsequently the variables could naturally be used in analyzing their effect on the equipment failure-rate, which could provide valuable information for preventive maintenance operations and service sales. The four suggested variables are:

- The distance to uncontrolled environment? – Preferably given in meters, or some other easily verifiable unit. In case the given value is 0, the next variable may be unnecessary
- The controlled environment deviates from standard indoor conditions (dust, cleanliness, humidity, temperature)? – Preferably given as a yes/no, maybe enable the option partly, but require a specification on which environmental factor deviates.
- Primary usage purpose of equipment? – Two industry-specific options
- Prone to user misbehavior? - Preferably given as a yes/no

This design proposition would however only remove (most of) the faulty operational environment assessments caused by obliviousness, while modifying the maintenance plans is still fully possible. The overall effect however is expected to be in improved information quality, with a possible indirect effect on over- and under-maintenance in combination with *DP1: Enable maintenance plan learning through utilizing event-data*.

To further complicate issues, as mentioned above the operational environment may vary between some main component instances, which represents the other part of this challenge. However, the prime source of problems with the main component in question, were suspected to rise from differences in usage intensity, resulting in different wear out-rates. The work-module granularity was thus suspected to cause waste in the form of under-maintenance of some instances, and over-maintenance of the remaining instances. Hence, the following design proposition:

> ***DP6: Increase the granularity of the IBI of the problematic main component work-module***

The implementation of this design proposition is further encouraged by the fact that the main component in question has a relatively high maintenance resource requirement, and is subjected to a proportionally large share of the total equipment failures. The first step would be to perform a comparative analysis on the two plausible different increments in granularity, namely further dividing the main component into (1) primary- and secondary-instances of the present main component, or (2) individual instances of the present main component.

The preferable course of action could be determined by the differences in usage intensity within the secondary main component instances. With neglect able differences, the first option is preferable, as its implementation with the current maintenance management systems is expected to be easier. With noticeable differences, the effects and requirements of implementing the second option should be further explored. When implemented, this design proposition can be expected to have a noticeable impact on over- and under-maintenance.

Moving to a pull-type service provisioning (as suggested in the following design proposition, *DP7: Classify spare parts based on the expected failure cause)* would also effectively solve this problem as long as the parts were traceable to the main component instances at the customer site. Eventually a fairly simple solution for this problem could present itself, as information on main component instance usage can be attained through remote monitoring, which can be combined with a work allocation based on usage intervals.

6.4 The preventive maintenance service operations are mainly push-driven

A general trend in maintenance, also seen at CaseCo, is an increased reliance on instrumentation monitoring the equipment usage and condition (remote monitoring). Constituting a move from push- to pull-driven preventive maintenance, there is a fundamental change from preventing failures that can happen in the near future, to preventing failures that will happen in the near future. While the context specific characteristics of CaseCo currently inhibit wider introduction of remote monitoring, there are two improvements which can introduce elements of pull-driven preventive maintenance without additional instrumentation:

DP7: Classify spare parts based on the expected failure cause and link them to the equipment where they are installed

The demand for maintenance arises in single parts, which forms the basis for the aggregated system demand for maintenance (see Murthy et al. 2008), which is synonymous to the maintenance intervals discussed above. Based on the different expected failure causes, spare parts can be classified as calendar parts, wear parts or spare parts. Where calendar parts are typically safety related parts, replaced well before their statistical end of life. Further, the term wear part is used in the sense of a part subjected to irreversible (failure cannot be postponed by PM) wear.

The installed calendar, wear and spare parts (which are part of the event data) can be connected to the item information, through reference data (Ala-Risku 2009). While it would be useful to be able to trace the part instances (in case of manufacturing errors), the only needed information is when they have been changed. This way, the installed parts could then in case of calendar and wear parts "announce" when they are approaching their calendar based, or statistical end of life.

Considering that the demand for preventive maintenance arises from single parts, any information about these single parts could probably be utilized to improve maintenance service operations, provided that they can be linked to the equipment where they are installed. This would essentially be a step towards leaner service operations, as part-announced replacements would introduce an element of pull into the service operations. However, the service base turnover might in some cases render this design proposition unattractive (especially with safety-related parts, where "replace by 1/2014"-type sticker solutions ensure information transfer in case the equipment changes service base).

Another opportunity to introduce pull into the service operations is to establish a communication channel to a decision-logic which is continuously, but unconsciously monitoring the equipment, hence our final design proposition (DP8):

DP8: Convert some call-outs to PM visits and service repairs, through crowd-sourcing

While a service technician visits the equipment with predefined intervals to confirm and restore the condition of the equipment, the user decision-logic is continuously in contact with the equipment. Despite the fact that it takes a maintenance technician to identify impending failures, most of the inspection points that the maintenance technicians check, are also visible to the user. Although theoretically possible, the idea would not be to have the user perform preventive maintenance inspections or checks, but simply to share their user experiences, them being good or bad.

This feedback channel would be implemented through mobile access & interaction technology[48], with unique identifiers for equipment individuals. This would enable the user; provided he has the scanning software, to give direct feedback which is automatically linked to the equipment (see Figure 15, below). Provided the frontend of the reporting system is appropriately designed, the user should be able to report negative (and of course also

[48] Such as UpCode™, see http://www.upcode.com

positive) user experiences, such as irritating or scary noises, unexpected equipment movement, dissatisfactory functional tolerances, flaws in signalization and lighting and so forth, with relative ease.

Figure 15 - An example of mobile access & interaction technology (directing the user to the feedback interface with the equipment ID pre-entered - http://feedback.caseco.com/feedback.form?equipm_ID:KDO330A79872191?user_ID:Jerrys_phone)

The backend of the reporting system could then, if needed, use light statistical analysis on the feedback, so that, depending on the usage of the equipment:

- One or a few feedbacks on the same observation would cause a notification to "check this" in connection with the next preventive maintenance visit.
- A higher number of feedbacks, originating from different users would lead to a separate, but non-critical planned visit or a shortening of the time until the next preventive maintenance visit.
- A radical number of feedbacks by different users that could for example affect the safety of the users could lead to action comparable to a call-out, perhaps preceded by a confirmation of the problem with the customer.

Additionally the backend could use a "peter and the wolf"-type of logic, where a false alarm would lead to an increased threshold for response next time.

This design proposition would improve predictability of service operations through improved service base awareness resulting in some reactive maintenance being converted into proactive maintenance. By creating a direct link to the equipment users, CaseCo could be expected to benefit from an increased understanding of user experienced value that eventually translates to customer value.

6.5 Concluding remarks on the identified challenges and the developed design propositions

A central theme in these design propositions is an expected reduction in over- and under-maintenance. The built-in assumption when talking about over- and under-maintenance is that there is an optimal level of maintenance, or inversely, an optimal level of equipment failures. Due to the existence of random failures and unknown distributions, this optimal level of failures will never be equal to zero. Thus, in the case of CaseCo, there is a need to define a target call-out rate, while appreciating the decision's implications for service demand.

For field services in general, the existence of over- and under-maintenance challenges the way productivity is measured. Productivity can be seen as the ratio between front-office and back-office time, which in CaseCo roughly translates to time on-site and travel time.

The implicit assumption with this definition is that time on-site is productive, which is explicitly disproven by the existence of over- and under-maintenance. In literature on health care field services this is corrected by introducing a quality variable to the front office time (cf. Groop 2012), however, in preventive maintenance field services, this is applicable only to functional quality, as technical quality is evaluated over time.

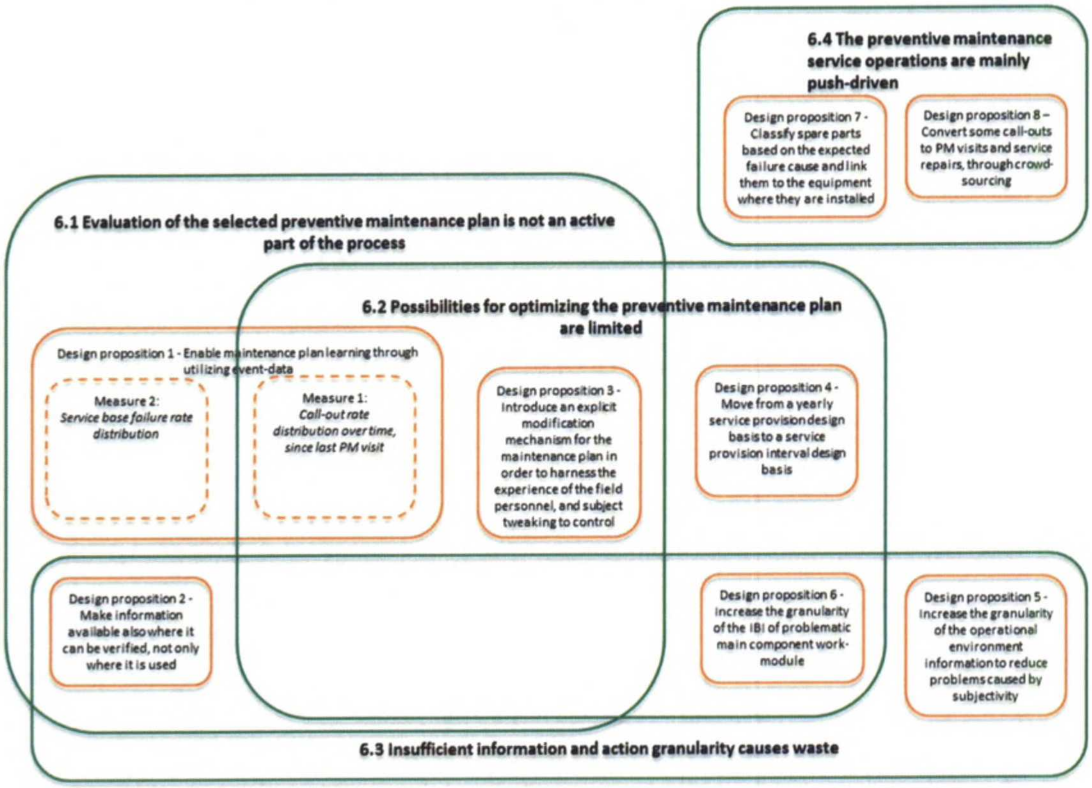

Figure 16 - Design propositions and challenge domains

If implemented, the Work-module level optimization of maintenance intervals suggested in *DP1: Enable maintenance plan learning through utilizing event-data*, would actually have a negative impact on productivity, in case *DP4: Move from a yearly service provision design basis to a service provision interval design basis,* is not implemented. According to how productivity is currently defined, an average reduction[49] of the time used per visit would increase the relative share of (non-productive) travel time. However, assuming an average reduction in visit time the technician is able to tend to a larger personal service base, so the number of equipment per technician measure would improve; especially in areas where productivity is high (i.e. the relative share of travel time is low). If the intervals were flexible however, *DP1: Enable maintenance plan learning through utilizing event-data*, would have a direct positive effect on the current productivity measures. This is not the only case of shared problem domains when associating design propositions with challenges, as is illustrated in Figure 16, above. Before moving on to section 7, we will look back at the research questions and objectives of the study, in order to appreciate what has been done, and what remains to be done.

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[49] Assuming a situation of average over-maintenance

In this section we have explored and answered RQ3: **How can the untapped potential of utilizing installed base information in preventive maintenance field services be reached?** With the reservation that there has been a clear focus on how the installed base information could better support the allocation of maintenance work. In the next section we will fulfill the additional requirement of quantifying the gap, imposed on the study by the selected approach "**Devising a framework for describing and quantifying the gap between the current and ideal use of installed base information, and applying it successfully in the case company context**". A short and concise answer to the third research question is presented below:

RQ3: **How can the untapped potential of utilizing installed base information in preventive maintenance field services be reached?**

As suspected[50] in the initial assumptions (section 2), significant potential was found in reducing over- and under-maintenance, through introducing a learning mechanism to the way the preventive maintenance plans are determined. Essentially this would comprise of a broader utilization of existing event-data combined with a transition from yearly maintenance plan definition to maintenance interval definition. Additionally, two cases of inappropriate granularity was found, where a correction is expected to lead to further reduced over- and under-maintenance.

The above implies doing things like they are done today, only better, while the arrival and increasing significance of condition monitoring solutions can be expected to change significantly the way things are done. However, as the case context characteristics give reason to expect a relatively slow adaption of these technologies, a different approach for moving from push- to pull-service provisioning was suggested through consolidating item and event data and through implementing a crowd sourced user-driven maintenance approach.

In the next section we will perform a detailed analysis on *DP1: Enable maintenance plan learning through utilizing event-data*, based on the service history extracts provided by CaseCo. Being the third and final stage of the analysis, this is where we will attempt to quantify the gap which is filled trough implementing design proposition 1.

[50] With a slight risk that we are dealing with a self-fulfilling prophecy

7 Gap analysis of design proposition 1

In this section we will analyze actual CaseCo event-data, in an attempt to quantify the gap between the way things are done today, and a situation where *DP1: Enable maintenance plan learning through utilizing event-data,* would be implemented. As mentioned previously, the preventive maintenance interval optimization procedure presented in subsection 7.2 is not fully compatible with the yearly maintenance activity allocation, but should be implemented together with *DP4: Move from a yearly service provision design basis to a service provision interval design basis.*

We will begin with a general presentation of the provided service data in subsection 7.1, where data-set special characteristics will be discussed to the extent they affect the upcoming analysis. We will then proceed to the measures in subsections 7.2 and 7.3. In both subsections a brief recap of underlying theory and relevant previously presented findings will be presented. In section 7.4 we will slightly modify the latter of the previously presented measures, to get new insights. We will then conclude with a recap of the analysis in subsection 7.5, where I will also present the concluding remarks for this section.

7.1 Data preparation

Two different sets of event data, one from Northern Europe, and one from Southern Europe were analyzed. To support the analysis, information of the technical specifications of the equipment were delivered along with their respective preventive maintenance plans. To facilitate computational limitations, the analysis was limited to six main components, which we shall call main components C, D, L, M, S and Z.

A considerable amount of time was spent with preparing the data for analysis, through cleaning and combining the data sets. When this was done the remaining population consisted of 1892 equipment individuals subjected to almost 50000 service events during the two different timespans[51].

The two regional populations were roughly the same size, and event data was supplied for periods of similar length. The differences in population sizes should be considered negligible, especially as data was mainly processed as equipment yearly averages. Further, the main comparisons between the populations were not made on absolute, but on relative terms, through comparing the shape of curves, rather than their absolute differences.

The relative number of call-outs was significantly higher in the Southern European sample. Further analysis reveals that the higher call-out rate is distributed[52] fairly evenly over the main components, with 35%/65% regional shares respectively, with Northern Europe having the smaller share of call-outs. There are however two exceptions to this rule, where the first is main component M, with a 50%/50% distribution[52], and the second is main component D, where the distribution[52] is close to 20%/80%. The latter exception is explained by an average technical difference in the populations.

[51] 2 years and 2 months for Southern Europe, 2 years and 6 months for Northern Europe
[52] Expressed as "Northern Europe / Southern Europe", and not adjusted according to population size

Another possible reason for the higher average call-out rate in Southern Europe is manifested in the higher average usage intensity of the population. There are also average differences in the operational environments; however, there were regional differences in how the variable was used. Further, recalling our previous discussions on the ambiguous interpretation of the environment variable, more initial trust was put in the usage intensity variable.

From the maintenance plans it was clear that Southern Europe was regulated, with the requirement of 12 annual visits. Northern Europe however was free of this type of regulation, with the typical annual maintenance plans containing 3 or 4 visits. This difference is valuable as it allows us to study the effect of regulation on the preventive maintenance performance. Based on the differences in call-outs, we can fairly safely assume that an increased amount of visits does not equate to fewer call-outs. A more relevant measure here is perhaps the share of prevented failures of the total amount of failures[53], as we could assume that more frequent visits would detect more impending failures. The numbers do not support this however, where the share[52] of prevented failures is 39%/35%, with Northern Europe having the higher number.

Based on the cleaned data, the analysis of the two measures proposed in *DP1: Enable maintenance plan learning through utilizing event-data*, were performed. First the data was analyzed based on three principal variables; event type, timestamp and affected main component. Based on these, the event intervals were derived for the *Call-out rate distribution over time since last preventive maintenance visit* -measure. For the *Service base failure-rate distribution* -measure, the average yearly failure-rates were extracted for the selected main components, and then compared to the preventive maintenance actions which were also extracted for the selected main components. After this, the Service base failure-rate distribution analysis was modified in order to analyze the effect of different amounts of preventive maintenance visits on the failure-rate distributions, named the *Effect of preventive maintenance*. Now, in hopes that the reader has gotten a feel for the data, we will proceed to the analysis of the two measures, preceded by a concise conceptual description of each measure.

7.2 Call-out rate distribution over time since last preventive maintenance visit

As previously mentioned, preventive maintenance has two functions; postponing wear-out failures, and detecting impending failures. The wear-out failures, being mainly a concern with mechanical components have been illustrated from a theoretical perspective by the rising end of the bathtub-curve (Figure 8, page 32). Thus, from a service provision point of view, the wear-out failures are minimized through timing your preventive maintenance to, or before the point when the wear-out phase is initiated. By performing preventive maintenance, the condition, or the failure-rate of the equipment is restored to a historical state, effectively postponing the initiation of the wear-out phase with a given amount of time. This effect on the equipment failure-rate is illustrated in Figure 17, page 66.

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[53] Call-outs were interpreted as occurred failures, while Service repairs were interpreted as prevented failures

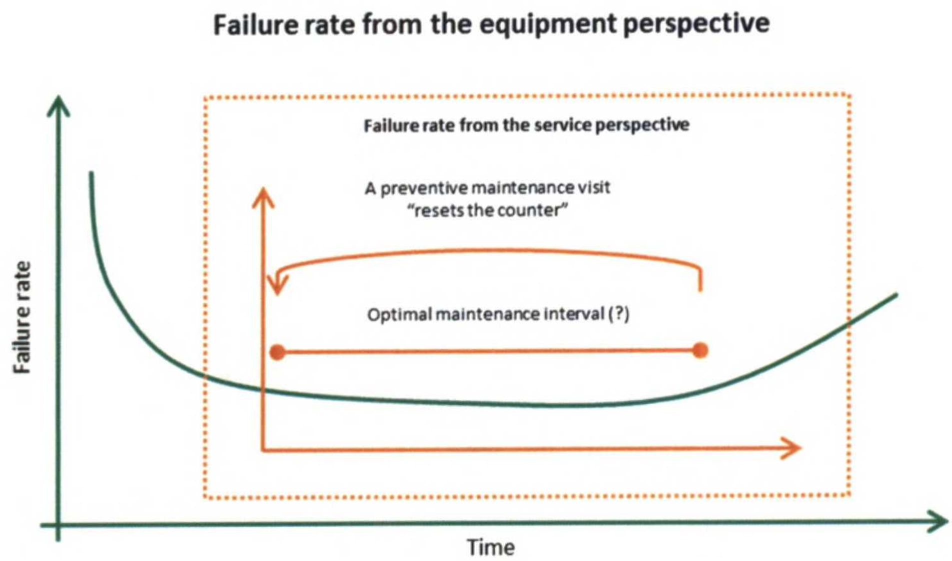

Figure 17- The service perspective to equipment failure-rate

From this figure we can further make two conclusions; the preventive maintenance interval should be equal to the additional time gained by postponement in order to maintain the average condition of the equipment, and the relationship between the maintenance interval and the resulting failure-rate is not linear. While this theoretical perspective can be utilized for maintenance interval optimization, the natural prerequisite is that the part, main component, system or equipment in question is subjected to wear-out failures. Thus, for example a constantly rising failure-rate would translate to a linear relationship between the maintenance interval and the resulting failure-rate.

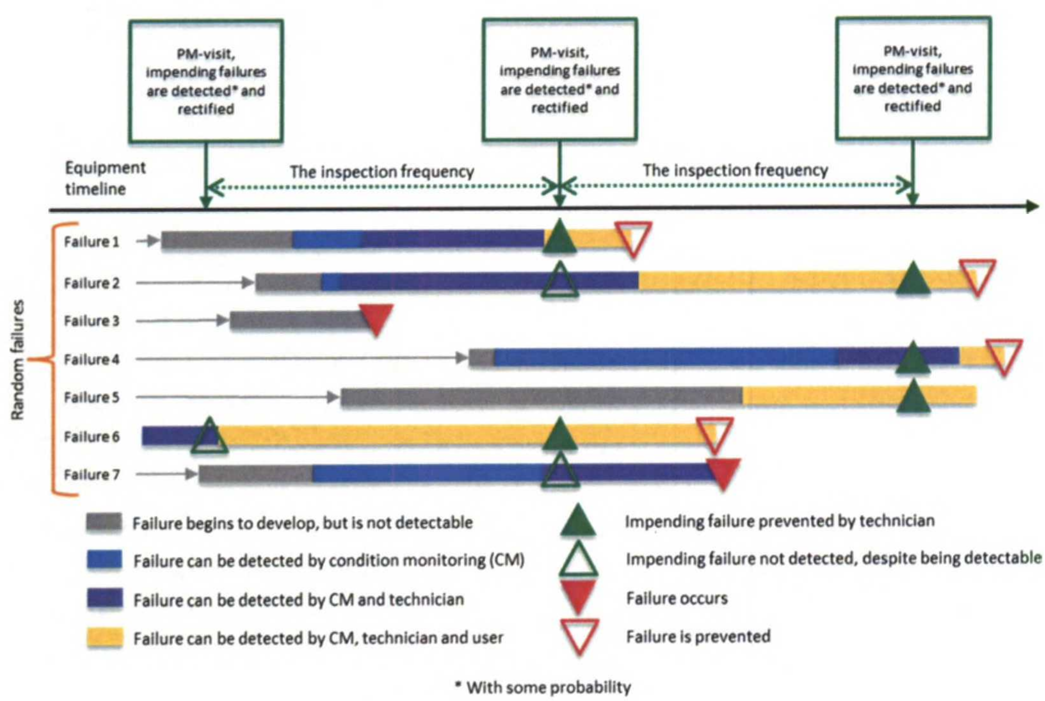

Figure 18 - The effect of preventive maintenance on impending "random" failures, defined by failure visibility

With detecting impending failures, we aim to prevent failures which cannot be postponed. This distinction is important, as many of the impending failures, in the way the term is used here, are also wear-out failures (but they cannot be postponed). Impending failures are, from a theoretical perspective, preventable random failures. In this case the failure visibility plays a crucial role, as is illustrated in Figure 18, above. Through this figure the reader should be able to comprehend the effect of adjusting the maintenance intervals. However, also consider the effects of implementing a condition monitoring system, or the user-driven maintenance approach elaborated in *DP8: Convert some call-outs to PM visits and service repairs*.

The effect of adjusting the preventive maintenance interval on the detection of impending failures is harder to evaluate. As we can see from Figure 18, if we fix the first PM visit and increase the intervals, more failures will occur. However, we can also see that the technician's ability to detect failures is a critical factor considering what impending failures are allowed to develop to failures. Assuming the technician is good at detecting impending failures we can expect that when increasing the preventive maintenance interval, the occurred failures will be concentrated to the end of the interval. Thus the relationship between increasing the maintenance intervals and the resulting failure-rate is directly dependent on the technician's ability to detect impending failures. Here a poor ability to detect would translate to a linear relationship, while a good ability to detect implies the existence of an optimal maintenance interval. This of course only applies to the failures which actually are detectable during a "long" timespan, as for example failure 3 in Figure 18 is completely unaffected by changes in the preventive maintenance interval.

The common factor for both of these functions (wear-out failure postponement and impending failure detection) is that the preventive maintenance interval essentially defines their outcome. Thus, utilizing event data type and timestamp, analyzed separately for each main component the preventive maintenance intervals were taken into inspection. This was realized by creating several different counters to the calendar based data (time-stamps), which were reset according to rules based on event type and main component. The resulting intervals, which were resolved for each equipment individual and main component, were then aggregated, resulting in a failure- and PM visit-rate over time representation. This allows us to analyze the effect of adjusting the PM interval on the failure-rate. A conceptual illustration of this is presented in Figure 19, page 68.

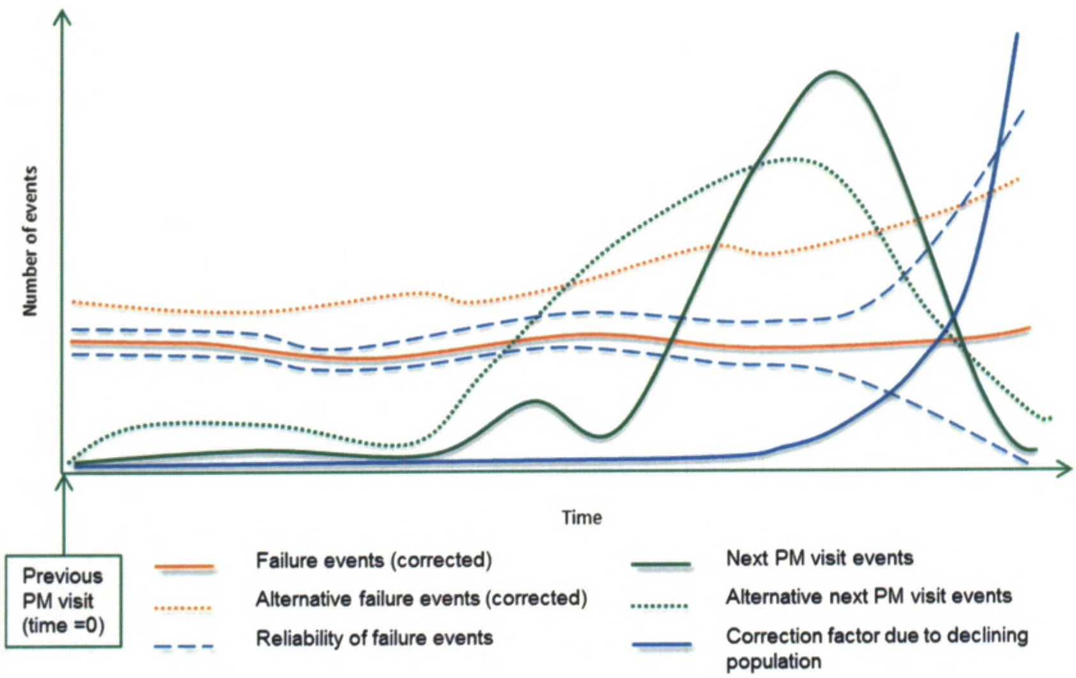

Figure 19 - Call-out rate distribution over time, since last PM visit

The orange and the green line represent the occurrence of failures and PM visits respectively, since the last PM visit. As the PM interval population declines, a correction factor (represented by the blue line) is needed to make the failure-rate comparable over time[54]. This correction factor however also weakens the statistical reliability of the failure-rate curve when the average preventive maintenance interval is passed. This reliability region with respect to the failure-rate at a given point of time is represented by the dashed blue line.

To further illustrate the applicability of this measure, an alternative failure event and next PM event distribution has been added in Figure 19, represented by the dotted orange line and dotted green line respectively. The solid orange line represents a situation where the failure-rate does not rise over time, implying that a reduction in intervals will not produce a corresponding reduction in failure-rate. The dotted orange line in turn represents a situation where the failure-rate rises over time, implying that a reduction in the preventive maintenance interval will lead to a corresponding reduction in the failure-rate.

With the Next PM visit distribution, the alternative PM visit distribution is included to illustrate the precision of the timing of the next PM visit. Here a wider and flatter distribution implies a poorer visit precision, and vice versa. This highlights the fact that despite "fixed" preventive maintenance intervals, the actual preventive maintenance intervals will still vary to the extent illustrated by the distribution. Considering the use of this measure, the interval precision has an impact on the correction factor, as a worse precision will lead to increased uncertainty in the failure-rate distribution. When comparing data from the two regions on this point, we can see that the precision of the visits is

[54] As a failure in a given interval cannot happen after the next PM visit, it instead becomes an event in the next PM interval.

considerably higher in Southern Europe, which is a natural cause of the 12-month regulatory visit requirement.

With this being said, it is time to move to the analysis on the actual data. Of the six main component work-modules, data for three different main component work-modules will be presented here, while the complete analysis is available in Appendix 1 - Call-out rate distribution over time, since last PM visit, all analyzed main components. The presented main components were chosen based on that, combined they illustrate most of the interesting findings in the analysis, and thus provide a good foundation for discussion. The data is always presented from both regions, as both regional differences and similarities are valuable. Absolute numbers will not be presented, as they are confidential and not relevant considering the analysis. Note that due to the weakening reliability of the data towards the end of the typical maintenance intervals, call-outs subjected to the correction factor have been limited to a three sigma deviation from the statistical mean.

In all interval analysis for both Northern- and Southern European main components, we have two distinct main peaks in the PM to PM distribution. The explanation for the peaks is naturally derived from the fact that for the selected main components, 1-2 yearly work-modules is typical. This is a clear deficiency in how the analysis was performed, as a separate analysis for the equipment subjected to different amounts of PM would, in retrospect, have been more appropriate.

Another smaller shortcoming of the analysis is that while service repairs were sometimes performed in connection to the PM visits, no distinction between such visits and "plain" PM visits were made. This means that the PM visit does not always postpone the wear-out phase, but in some cases reverts the part in question to the beginning of the bathtub-curve (see Figure 17, page 66), exposing the part to infant failures.

Call-out rate distribution, main component C

The data from Northern Europe is presented in Figure 20, while the corresponding data from Southern Europe is presented in Figure 21.

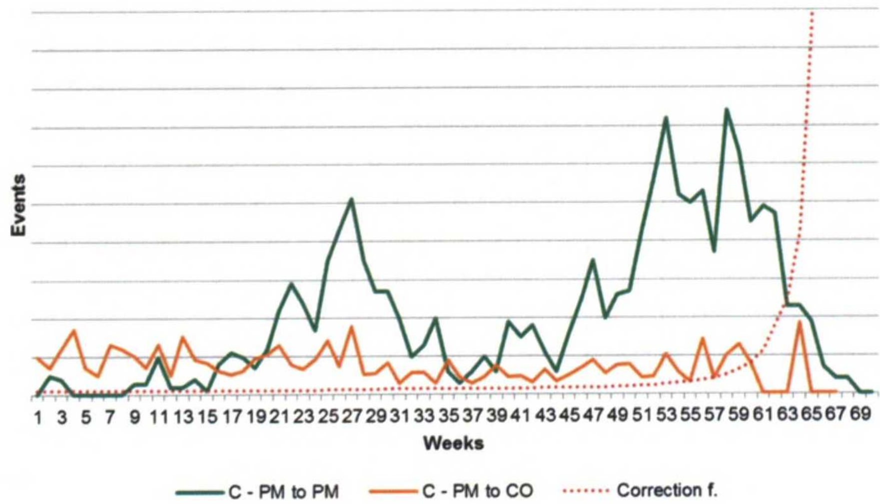

Figure 20 - Call-out rate distribution over time since last preventive maintenance visit, main component C, Northern Europe

When inspecting the failure-rate, we can see dip between the first and the second PM peaks, which is likely to be caused by differences in operational environment and usage intensity faced by the equipment. On the other hand, the Southern European relatively higher but declining call-out-rate in the beginning (shortly after a PM visit) could also be partly explained by infant failures. Whether we can see a rising call-out trend when the intervals get longer, is debatable. There seems to be a slight rise at the end, especially in the Southern European data; however, hasty conclusions should not be drawn, as the large correction factor weakens the statistical reliability.

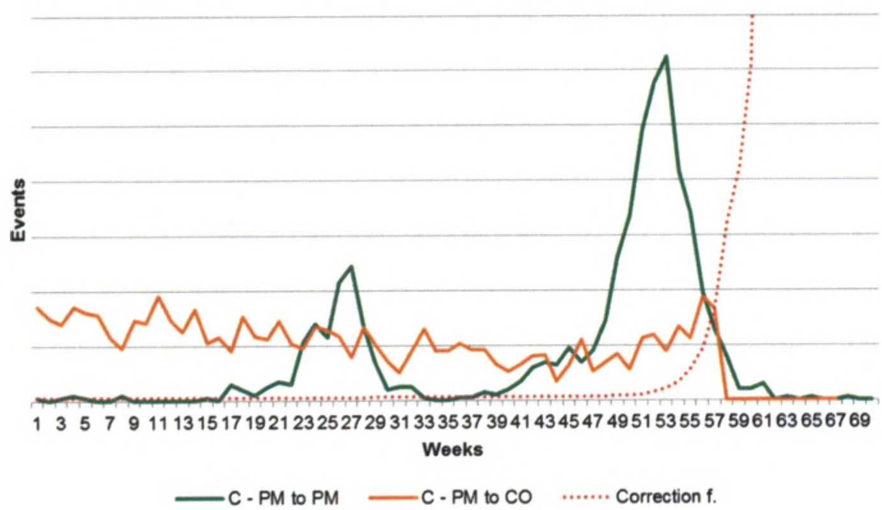

Figure 21 - Call-out rate distribution over time since last preventive maintenance visit, main component C, Southern Europe

Call-out rate distribution, main component L

The data from Northern Europe is presented in Figure 22, while the corresponding data from Southern Europe is presented in Figure 23.

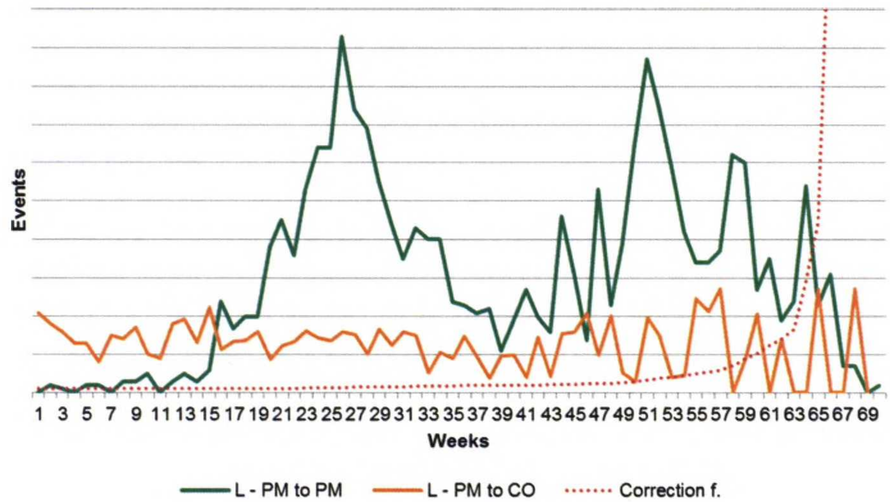

Figure 22 - Call-out rate distribution over time since last preventive maintenance visit, main component L, Northern Europe

Here we can see roughly the same phenomenon as with main component C; however the failure-rate dip in the middle is present only in the Northern European data, and is somewhat dampened due to the poor precision of PM visits. In the Northern European sample we can see a rising trend when approaching the longer maintenance intervals; however, the reliability of the finding is again questionable due to the impact of the correction factor. The precision of the PM visits appears to be slightly worse when comparing the North European distribution with that of main component C. A slightly elevated call-out rate right after the previous PM visit can be interpreted from both figures, whether it is statistically significant remains unexplored.

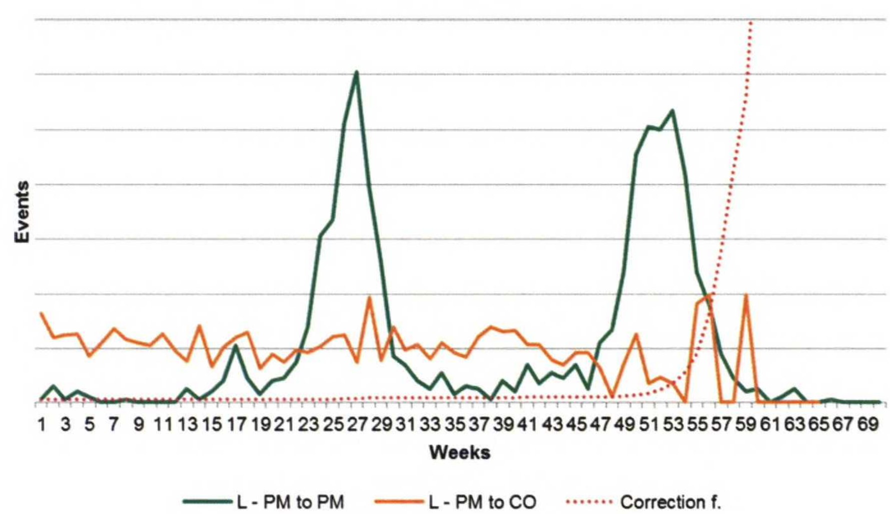

Figure 23 - Call-out rate distribution over time since last preventive maintenance visit, main component L, Southern Europe

Call-out rate distribution, main component S

The data from Northern Europe is presented in Figure 24, while the corresponding data from Southern Europe is presented in Figure 25.

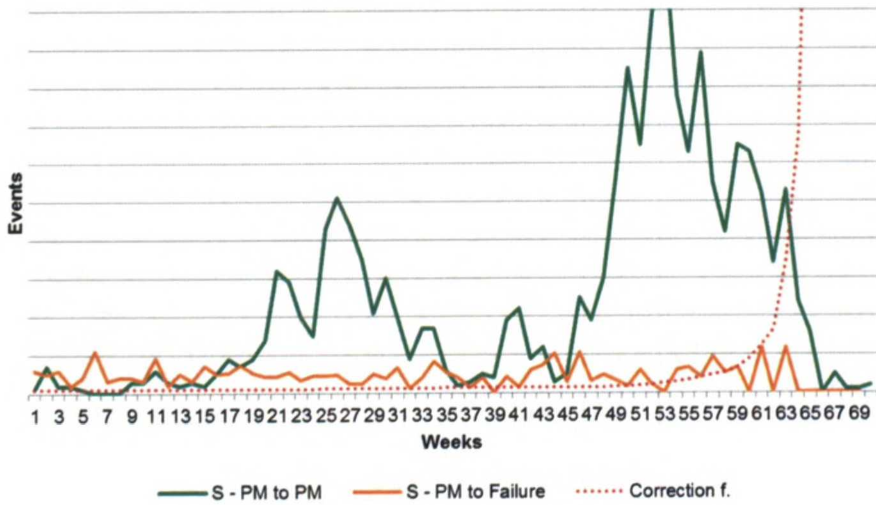

Figure 24 - Call-out rate distribution over time since last preventive maintenance visit, main component S, Northern Europe

Where the two previous main components have shown discussable characteristics, main component S shows a relatively stable call-out rate through the length of the preventive maintenance intervals. With the exception of a possibly slightly rising call-out rate towards the end of the preventive maintenance interval in the Southern European case, there is not much to be noted. These data samples are also representative considering the remaining main components M and Z, and while main component D does have a general declining trend during the preventive maintenance interval, it was moved to the appendices due to the regional differences concerning it, mentioned in the Data preparation-subsection.

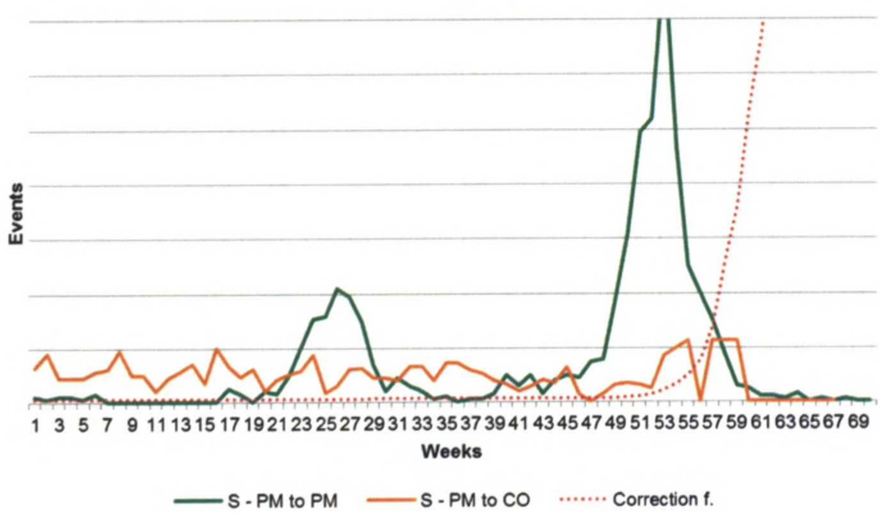

Figure 25 - Call-out rate distribution over time since last preventive maintenance visit, main component S, Southern Europe

7.3 Service base failure-rate distribution

Where the *Call-out rate distribution over time since last preventive maintenance visit* - measure can be used to find the optimal maintenance intervals on an aggregate level, the measure does not produce equipment specific recommendations. For this, a simple measure was proposed as a part of *DP1: Enable maintenance plan learning through utilizing event-data*. The service base failure-rate distribution was proposed to form the basis for a simple maintenance resource reallocation method. A demand and supply view of preventive maintenance is constructed through assuming that the annual number of visits could be seen as the supply of preventive maintenance, and the failure-rate could be seen as correlating with the demand for preventive maintenance. Thus, high failure-rate individuals would be moved to a group with more frequent visits, and vice versa, the low failure-rate individuals would be moved to a group with less frequent visits, as illustrated in Figure 26, below, while expecting that this would on average lead to an improved service base performance.

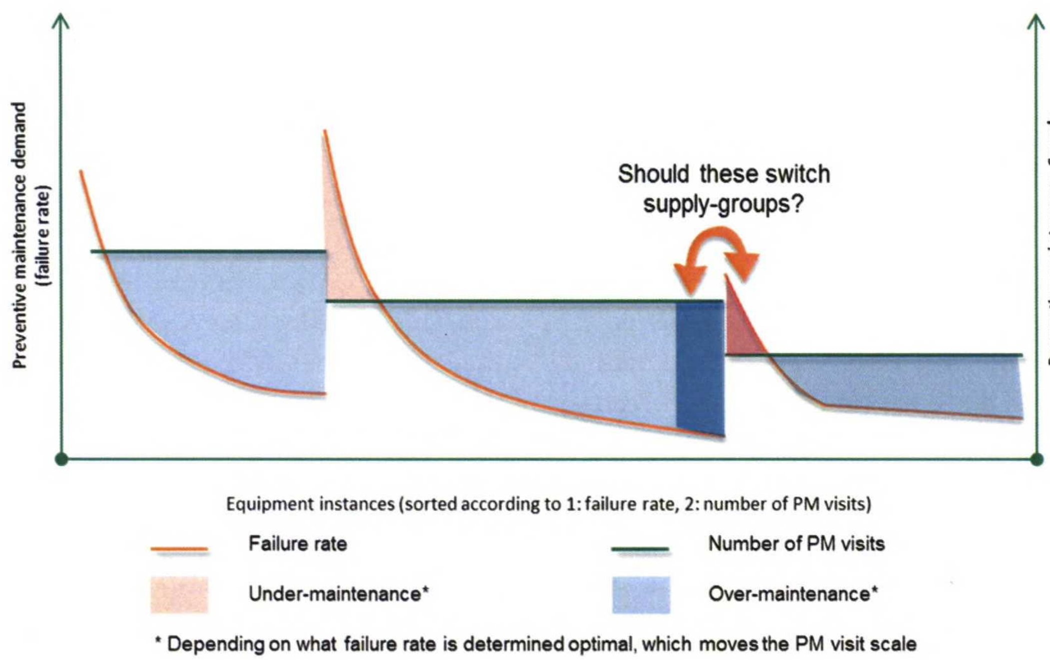

Figure 26 - Service base failure-rate distribution

While the apparent advantage of this approach is that it can be fairly easily implemented with the current PMAS, the drawback is that the evidence for correlation between the supplied amount of preventive maintenance and the demand, or the failure-rate, is not consistent. When comparing the ratio between prevented failures and total number of failures, we can see a contradicting trend in the Northern European data, where increased number of visits has an inverse relationship to the failure detection rate. While these figures are related to impending failure detection, the effect of postponing wear-out failures is more difficult to evaluate. Here the Service base failure-rate distribution is presented only for main component L, while the full analysis is available in Appendix 2 - Service base failure-rate distribution, all analyzed main components.

Service base failure-rate distribution, main component L

The data from Northern Europe is represented in Figure 27, while the corresponding data from Southern Europe is represented in Figure 28.

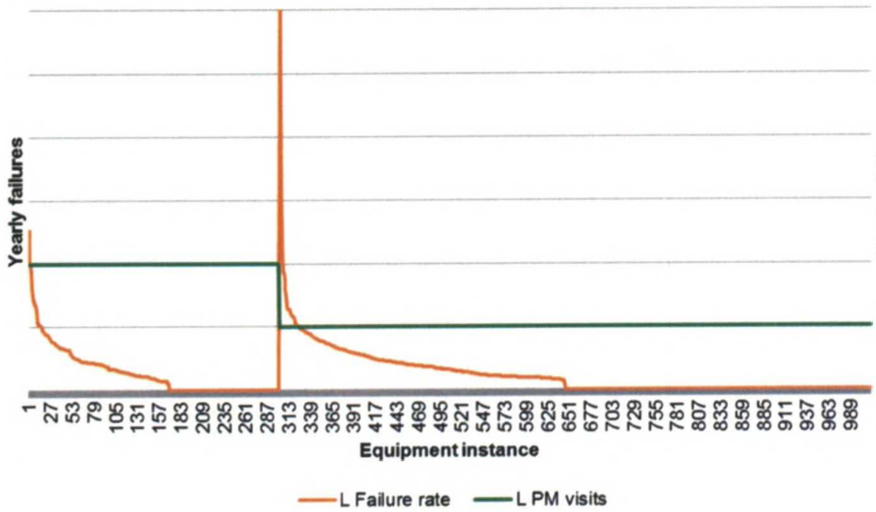

Figure 27 - Service base failure-rate distribution, main component L, Northern Europe

The data for main component L is a typical example considering the whole data set as it is presented by this analysis. The considerable differences in failure-rates within groups of the same amount of yearly visits can be interpreted as a sign of demand and supply mismatches. If these mismatches are not directly utilized for resource reallocation, they at least form a starting point for the proposed information validation mechanism (*DP2: Make information available also where it can be verified, not only where it is used*). When comparing failure distributions within and between regions, we need to remember that each data-point in this analysis is represented by an equipment individual, implying that sharp spikes, no matter how high, are likely to be non-significant. In general, the differences in the forms of the distributions are better revealed through the preventive maintenance effect analysis, to which we will move next.

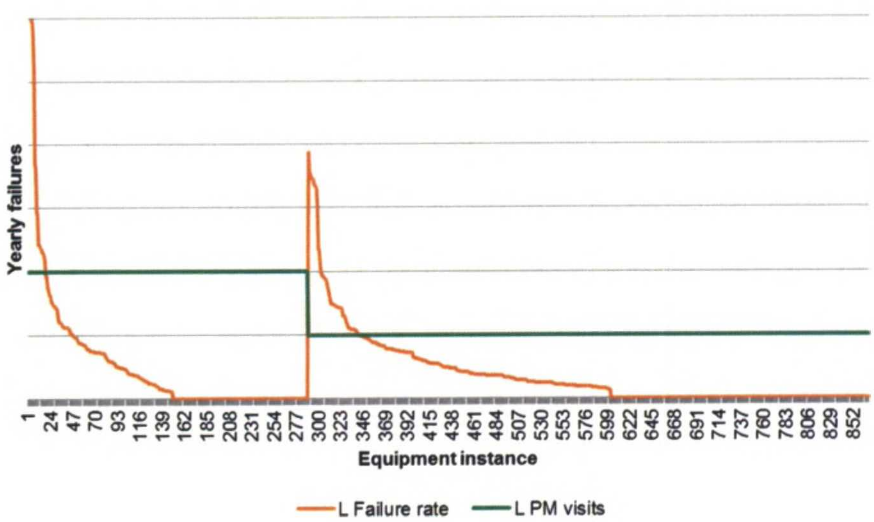

Figure 28 - Service base failure-rate distribution, main component L, Southern Europe

7.4 The effect of preventive maintenance

The *Service base failure-rate distribution*-measure shows differences in the distributions between the amount of visits for a designated main component, between different main components and between different regions. However, in order to better illustrate these differences; the service base failure-rate distribution was further refined[55] to a *preventive maintenance effect analysis*, see Figure 29, below.

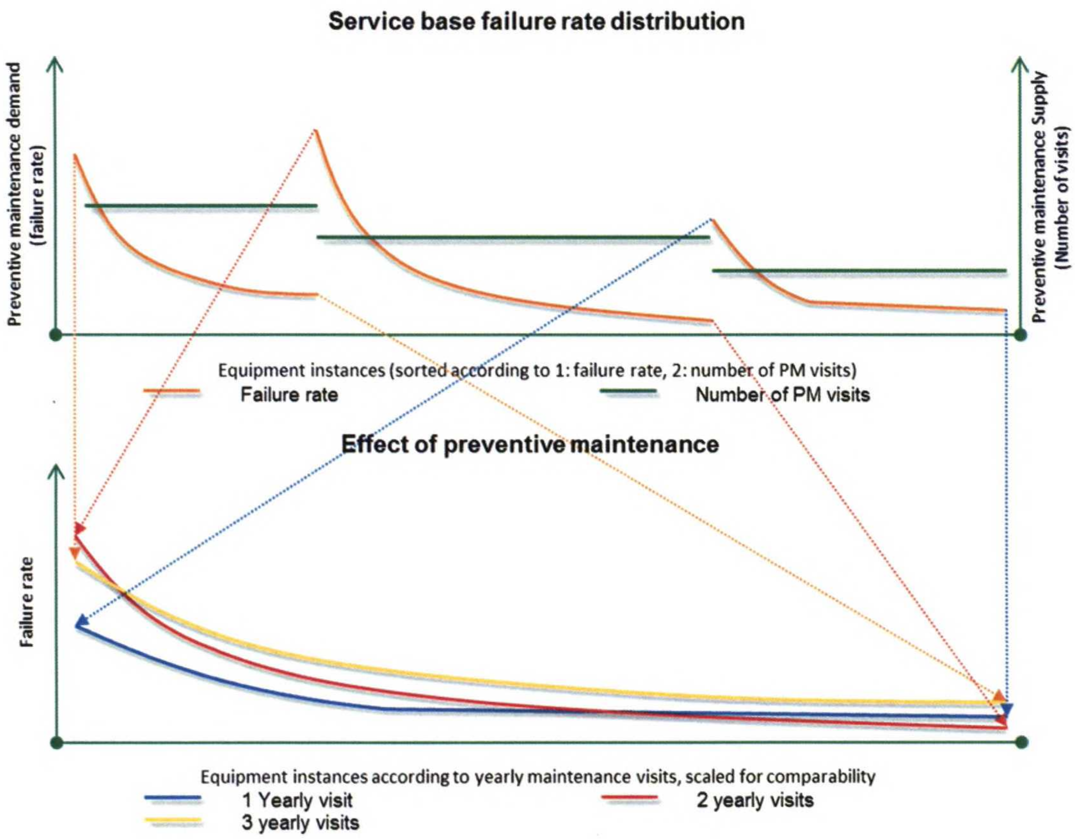

Figure 29 - Preventive maintenance effect analysis derived from service base failure-rate distribution

The preventive maintenance effect analysis uses the same data as the service base failure-rate distribution, but presents the rate as separate distributions (according to the number of annual visits), rather than a "continuous" distribution, scaled for comparability. Through this measure we can compare the failure-rate distributions between equipment subjected to different amounts of preventive maintenance. Despite being named preventive maintenance effect analysis, the causality link should always be questioned. Here the *preventive maintenance effect analysis* is presented for main components C, S and Z, while the full analysis is available in Appendix 3 - Preventive maintenance effect on failure-rate distribution, all analyzed main components.

[55] Note that this is basically the same measure as *Service base failure-rate distribution*, using the same data, the difference is in representation

Preventive maintenance effect, main component C

The data from Northern Europe is presented in Figure 30, while the corresponding data from Southern Europe is presented in Figure 31.

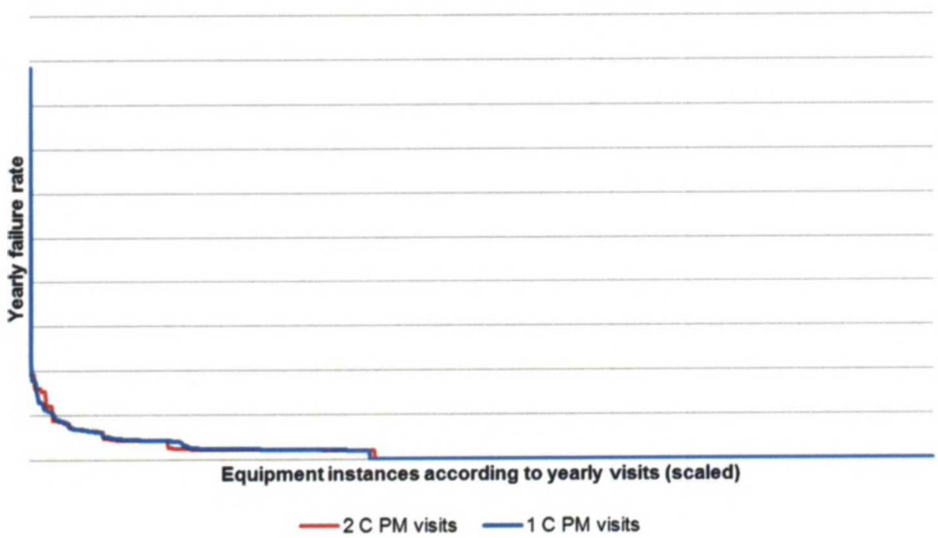

Figure 30 - Preventive maintenance effect, main component C, Northern Europe

In the Northern European data we can see a roughly identical distribution between different visit frequencies, while the Southern European data shows clearly elevated yearly failure-rates for the 2 annual visits distribution. It would thus seem that preventive maintenance has a greater impact in Northern Europe. Alternatively is can be an indication of harsher conditions for the Southern European equipment, or more likely, a combination of both. As strict causality cannot be determined, these figures should mainly be considered as an encouragement for further studies. Before moving on, we will further note that main component L has similar distributions to these, with the same regional difference.

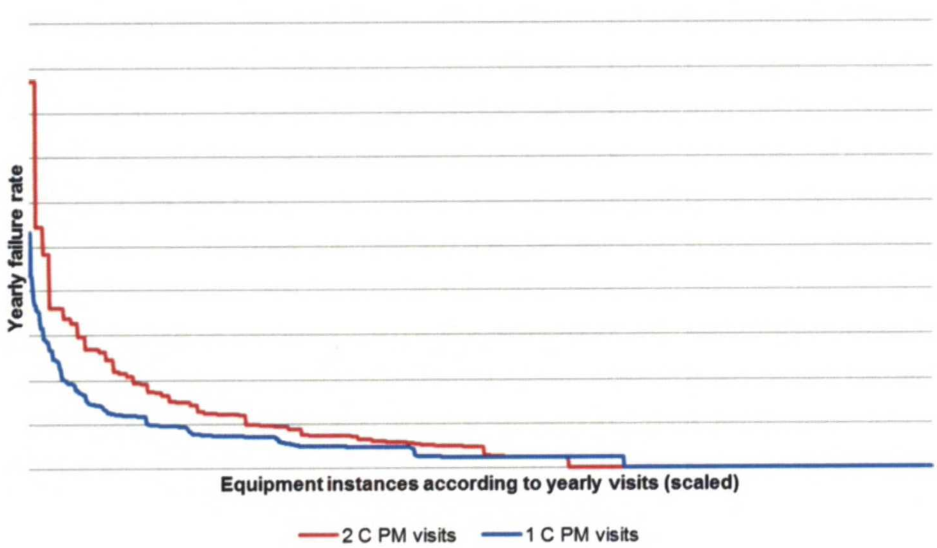

Figure 31 - Preventive maintenance effect, main component C, Southern Europe

Preventive maintenance effect, main component S

The data from Northern Europe is presented in Figure 32, while the corresponding data from Southern Europe is presented in Figure 33.

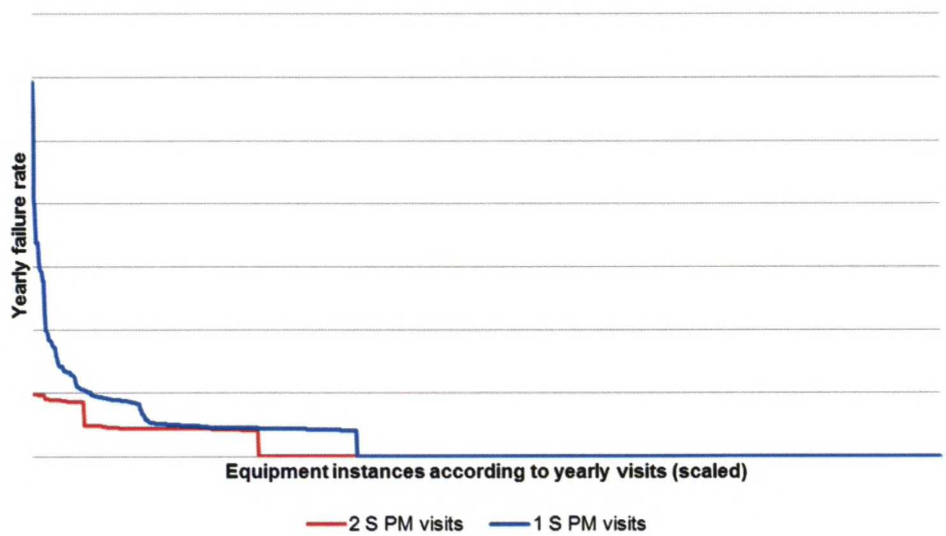

Figure 32 - Preventive maintenance effect, main component S, Northern Europe

Here Northern Europe shows a remarkable improvement from 1 PM visit to 2 PM visits, while Southern Europe has a roughly equal distribution for the two. While it is tempting to label the Northern European distributions as proofs of preventive maintenance effect, we should keep in mind that for main component S there is an exceptionally small share of equipment with 2 annual (main component) visits. A similar situation, with the same regional differences can be found with main component D; however, as previously mentioned, main component D is not fully comparable on a regional level.

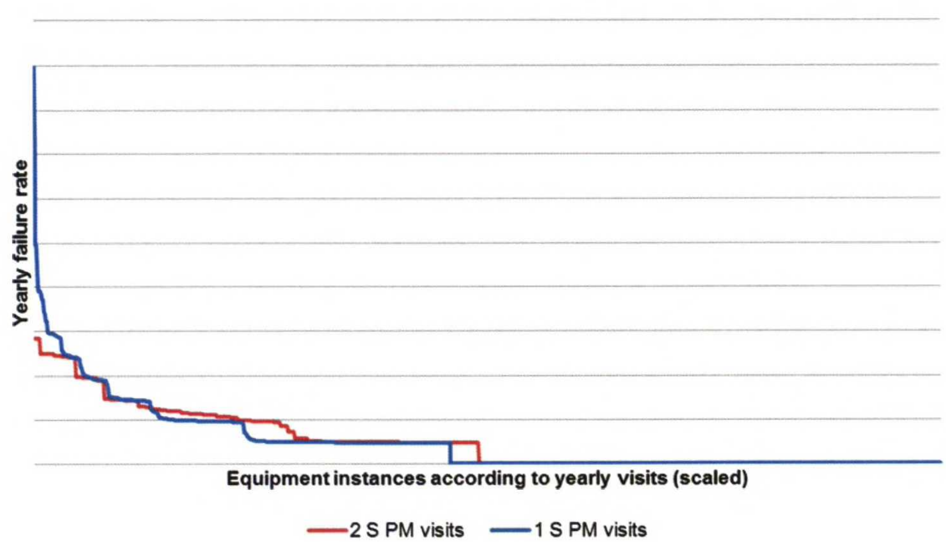

Figure 33 - Preventive maintenance effect, main component S, Southern Europe

Preventive maintenance effect, main component Z

The data from Northern Europe is presented in Figure 34, while the corresponding data from Southern Europe is presented in Figure 35.

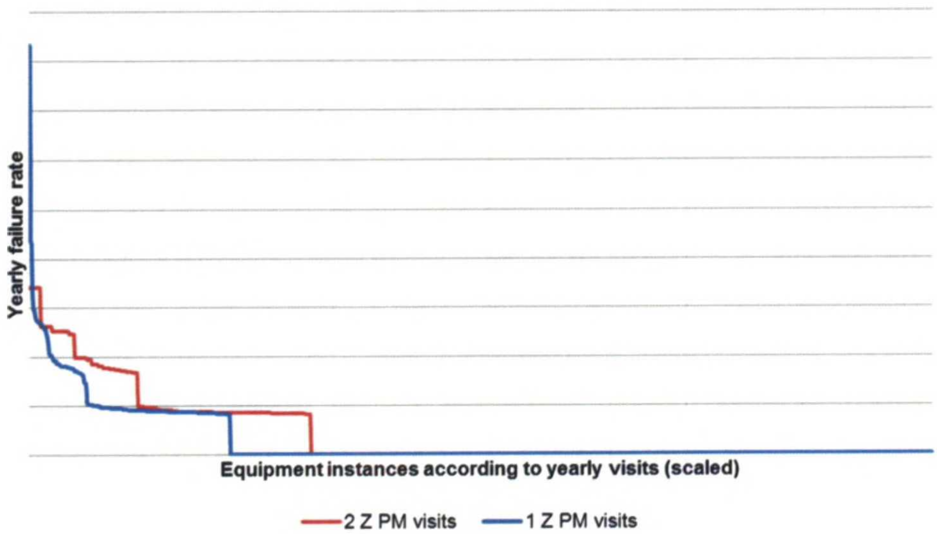

Figure 34 - Preventive maintenance effect, main component Z, Northern Europe

Here the distributions are fairly similar in cross-regional examination, with the 2 annual visits distribution topping the 1 annual visit distribution. This could be interpreted as preventive maintenance having no effect, or even worse, a negative effect on the failure-rate distribution. The regional similarity is fairly unique in this analysis, and is only matched by the similarity of main component M distributions; however, regarding main component M, more visits lead to a lower distribution. Further it is noteworthy that main component Z is the only case where Northern Europe has a worse failure-rate distribution for 2 annual visits compared to 1 annual visit.

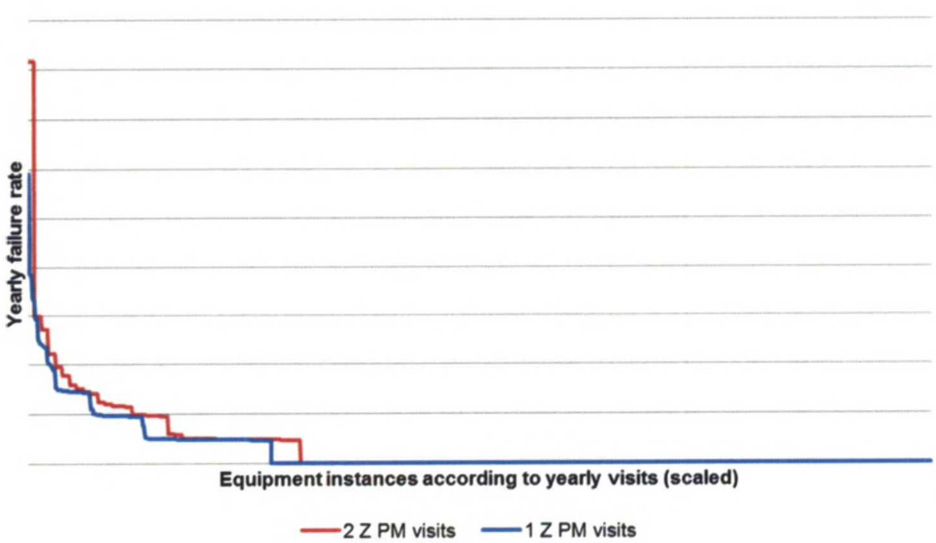

Figure 35 - Preventive maintenance effect, main component Z, Southern Europe

7.5 Concluding remarks on the gap analysis

Arising from the conducted interviews, there was a common suspicion that CaseCo is currently over-maintaining its equipment on average. Despite the suspicions, there was no way of proving this claim, as the random nature of failures makes over-maintenance challenging to measure. The two presented measures, which together form the first design proposition; *DP1: Enable maintenance plan learning through utilizing event-data*, constitute a method for measuring, and consequently proving potential over-maintenance.

The *Call-out rate distribution over time since last preventive maintenance visit* -measure shows the effect of adjusting the maintenance intervals, thus revealing over- and under-maintenance on an aggregate level. While being firmly anchored in theory, the detection and prevention of impending failures should be further investigated, at least through studying the effect of the technician's competence. The analysis shows a seemingly clear case of average over-maintenance, where a rise in the failure-rates with the longer intervals cannot be stated with certainty. The absolute amount of over-maintenance cannot however be determined, as it can only be revealed through slowly increasing the maintenance intervals, through the proposed learning mechanism. Based on the analyzed data however, it is safe to say that, due to no clear signs of increasing failure-rates, the maintenance intervals could on average be increased by 5-10% without a noticeable effect on the average failure-rate.

The *Service base failure-rate distribution*-measure addresses over- and under-maintenance on an equipment individual level. The analysis showed that the failure-rate distributions were quite similar independent of how much maintenance the equipment groups were subjected to. The distributions indicated possible cases of over-and under-maintenance in all preventive maintenance supply-groups. While the initial step would be to check the underlying assumptions embedded in the maintenance plan through the usage intensity and operational environment information, a subsequent re-allocation has to be supported by a learning mechanism which is able to evaluate the consequent change in performance. Considering the implementation of both of these measures, as the basis for a maintenance plan learning mechanism, the use of control groups to establish change performance is advised.

As we can see from the *Preventive maintenance effect* -curves, there seems to be differences in how different main components react to the operational environment, usage intensity and maintenance actions that they are subjected to. We cannot determine the involved causality with certainty; however, this would be a very promising area to conduct further research in. We can however say that the technical composition influences the failure-rate distribution, and consequently the demand for preventive maintenance. Being the source of the demand, the data on individual parts and types of main components becomes very important. Having this data would improve the accuracy of the maintenance interval analysis, provided that large enough populations exist of the analyzed specified main component types.

A relevant question at this point is; how much can you actually say based on historical data in the preventive maintenance context? From a theoretical point of view, we can say that the demand for maintenance is a function of technology, operational environment and usage intensity (Murthy et al. 2008). While there will be exceptions, with equipment occasionally getting "sick"[56], the demand for preventive maintenance[57] should remain fairly stable (with some main component specific variation), as long as these three variables remain unchanged. This can also be seen in the yearly changes in the number of failures (Figure 36, below).

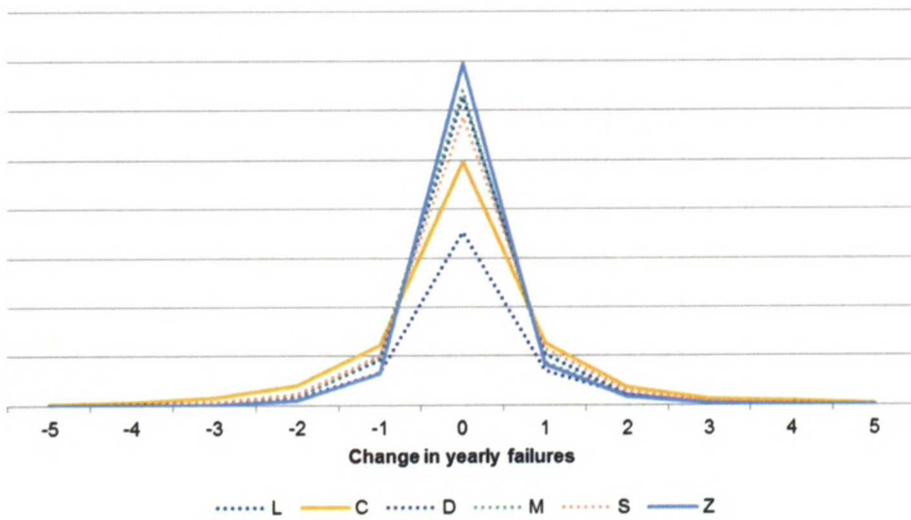

Figure 36 - The yearly change in the number of failures

As this part of the analysis was supplementary to the conducted study, many interesting things and perspectives were left unstudied. Thus, further analysis is recommended in order to validate or reject the findings presented in this section. Considering the entire CaseCo service base, the studied population is quite small, and while this analysis was concentrated in two regions, the regional differences should be analyzed more widely and explicitly as they will affect the effect of implementing the proposed learning mechanism. Also, as mentioned earlier, the preliminary analysis on preventive maintenance effect should be continued as valuable insights can be expected from this.

The Concluding remarks on the identified challenges and the developed design propositions in subsection 6.5 highlight a possible performance measurement paradox, preceded by a possible mindset dilemma. Acknowledging that all time on site is not equally productive is also the core message of this part of the analysis. Through this the already mentioned need to put a number on the desired call-out rate, becomes concrete. The combined results of these analyses should encourage CaseCo to move away from fixed maintenance intervals and a never ending pursuit of 0 call-outs. While this objective is noble per se, from a value-creation perspective, the desirable thing would be to balance resource usage and call-out rate, through finding the most efficient input-output ratio. The most efficient input-output ratio is unknown, but the analysis in this section shows that it is not the current input-

[56] A term used by the interviewees for equipment which unexpectedly start generating frequent failures

[57] Which is conducted to mitigate the effects of cumulative usage intensity and exposure to operational environment

output ratio. Further this analysis shows that the efficient input-output ratio varies between main components.

The analysis presented in this section could be characterized as an extension to answering RQ3: **How can the untapped potential of utilizing installed base information in preventive maintenance field services be reached?** Primarily motivated by the selected approach; "**Devising a framework for describing and quantifying the gap between the current and ideal use of installed base information, and applying it successfully in the case company context**". While this section does clarify the "how can the untapped potential ... be reached"-part of RQ3, its primary intention is to answer the question; should the untapped potential be pursued? The short answer to this is; yes, perhaps preceded by more detailed analysis of the proposed measures.

This concludes our analysis, and in the following two sections we will discuss the scientific implications of the findings followed by conclusions, where the central points of the thesis are summed up.

8 Discussion

The objective of the thesis was to uncover the value of installed base information. In retrospect we can say that the developed literature framework was proven a formidable tool for this purpose, in the sense that it was able to illustrate the contribution of installed base information in value creation beyond simple causal chains. Where the literature framework per se was not able to, or even intended to, quantify the value in a relevant measure, the closer analysis on one of the improvement suggestions was. The developed measures for identifying over- and under-maintenance thus complemented the literature framework through being able to show that CaseCo on average over-maintains its service base. These two tools, the literature framework and the measures, are the central contributions of this thesis, and in this section I will discuss them in the context of different fields of research drawn upon in their creation.

Servitization

The motivation of this thesis stemmed from the pressure on capital goods manufacturers to servitize. As a field of research, servitization is well established, with its roots back to the late 80's. This means that significant theoretical contributions are not likely to arise from single case studies. With this being said I claim that this thesis does make a valuable contribution to the servitization research stream, through providing a tool for servitizing manufacturers in aligning their information utilization with value creation. The need for tools and frameworks for managing servitization was stated by Baines et.al (2009), and considering the central role of information in service provision (Sampson & Froehle 2006; Vargo & Lusch 2004), the developed literature framework addresses a real and significant challenge in servitizing.

Another interesting consideration related to servitization also arises from this thesis. The in depth literature study in operational decision-making done in connection to developing the literature framework lead to a distinction between active and passive (or embedded) decision-making logics. This is important considering servitization, as a manufacturing operations management predisposition, or a manufacturing mindset, could result in a tendency for servitizing manufacturers to rely too much on passive decision logics. Arising from being accustomed to closeable systems with clearly defined borders, such a predisposition could lead to service efficiency and effectiveness deteriorating over time. While there naturally is a need for both types of decision logics, the developed literature framework essentially raises awareness of the passive decision logics, thus facilitating the creation of continuously learning service operations.

A third observation made related to servitization is one on performance measurement, which is closely related to the discussion on active and passive decision-making mechanisms. Again arising from a manufacturing mindset, it is conceivable that servitized manufacturers would concentrate their performance management efforts on *doing things right* rather than *doing the right things*. The stagnant mindset could be condensed to; we do what we do (as good as we can), and then the value is determined by the customer. Such a lacking embracement of the service-dominant logic (Vargo & Lusch 2004), and survival of the operand resource as a mental construct, would in service operations management logically lead to an emphasis on "functional performance management" (i.e. measuring that you are doing things right). While this was the case in the case company, it is quite likely that it was a preventive maintenance context specific phenomenon (cf. Blakeley et al. 2003), as measuring that you are doing the right things in preventive maintenance is not easy. If the phenomenon did exist in a wider context, it would translate to an efficiency dominant approach to developing operations on the expense of a value dominant approach. Assuming this, there could be significant strategic gains in being able to change emphasis.

Considering services on a general level, this thesis has elaborated on the scarcely discussed phenomenon of over- and under-service. While this is tightly coupled with the performance management issue discussed in the previous paragraph, the contribution of this thesis is that it has made the phenomenon explicit through detaching it from the vague concept of service quality. The existence of over- and under-service is context specific, and logically there should be a chance for over- and under-service to exist in all situations where the technical quality of the service is determined over time[58]. As the approach for quantifying over- and under-maintenance developed in this thesis is highly context specific, the contribution to the service stream of research is of a philosophical nature; in situations with postponed technical quality, the average "technical performance" can be controlled through aggregated instance histories, in a way which uncovers the relationship between service provision and service failures.

Preventive maintenance

On a context specific note, this thesis complements the existing work on preventive maintenance, as it takes a service provision viewpoint on the installed base, where the majority of prior work discusses preventive maintenance from an asset management viewpoint (for definitions, see subsection 3.2.3). The difference in talking about the service base, compared to the asset base, is that due to the larger equipment bases[59] the reliability of the equipment becomes susceptible to statistical analysis through aggregation. This in turn enables managing the preventive maintenance resource usage versus average equipment failure-rate ratio in a manner that seeks to optimize the ratio. This is the second core contribution of the thesis, with the disclaimer that the developed measures are not necessarily relevant in all preventive maintenance contexts. For example, in contexts where equipment criticality is high, finding the balance-point between over- and under-maintenance is not necessarily a priority, nor preferable, as the impact of maintenance resource usage might be minuscule compared to the impact of failures.

The conceptual basis for the developed measures is also an important contribution, as the idea of failure postponement in the sense that it is presented in this thesis, effectively ties the technician competence to equipment reliability. This is significant as previous research on preventive maintenance has been fairly technical reliability focused due to its manufacturing origins (cf. Jambekar 2000; Barlow & Hunter 1960; Nakajima 1988), thus focusing on the customer resource input, on the expense of the supplier resource input in

[58] This is the case in preventive maintenance, preventive health care, preventive social services, etc.

[59] Which, due to being technically similar, have a similar demand for preventive maintenance, differentiated by factors such as usage and environment

the inseparable service delivery. The key-assumption with the service view on reliability (see Figure 17, page 66) is that the technician leaves the site confident that the equipment will survive until the next visit. This assumption is at the crux of coupling the customer resource input with the supplier resource input, effectively moving from reliability- to a service-view on preventive maintenance.

A third contribution to the preventive maintenance research stream is the extension of user-driven maintenance to contexts beyond the manufacturing plant. Briefly presented as an alternative (cheaper) solution to continuous condition monitoring (in subsection 6.4), the idea of crowd-sourcing failure-detection in the form it is presented here is novel according to the best knowledge of the author. Uncovered by the concept of failure visibility, this approach to continuous condition monitoring could and should be considered in contexts where technical-, criticality- and service base dynamics render the utilization of technological solutions unfeasible at this time.

Before moving on to the fairly new research field of installed base information, we shall conclude our discussion on preventive maintenance with a philosophical observation. The introduction and growing popularity of condition monitoring solutions questions the relevance of the current classifications of maintenance. This arises from the question; if we know that something is going to break, is it still preventive or proactive maintenance? Put in other words, there seems to be a need for clarification of concepts related to maintenance, combined with a critical inspection of basis for classification of events. A good starting point could be the concept of failure visibility, as it seems that a failure actually occurring is no longer the single most important divider.

Installed base information

Installed base information, is a relatively new (explicit) field of research singled out by Ala-Risku (2009). Based on this thesis we can say that two characteristics are especially important considering all types of installed base information, namely; granularity and frequency. While this is also extended to maintenance action in this thesis, the two characteristics seem to be fundamental to intentional changes on the state of reality, as all challenges and opportunities found in the thesis, somehow relates to a mismatch in granularity or frequency. Thus, based on the thesis, we could expect that further research in systematizing the procedure of applying the literature framework, with respect to these characteristics, would be a powerful tool for identifying improvement potential in service processes.

More concretely the thesis contributed to the field of installed base information, through finding that event-data is at the core of constructing learning and adapting processes. As evident as it may sound, history provides an important reference point when attempting to improve the efficiency of operations. This naturally applies both to *doing things right* and *doing the right thing*, which was discussed earlier. The managerial implication is that event-data is crucial for efficient service operations, while the managerial and scientific follow-up question is; How should event-data be defined, collected and stored in order for it to support process learning in the best possible manner.

A third observation concerning the installed base information was regarding the collection of information, which seemed to be challenging, especially in situations where the one collecting the information did not use it himself, nor grasped how it would be used. Especially in field services, where the need for information is high, the question of where the decisions should be made, by whom, and based on what information, poses and information processing dilemma (cf. Galbraith 1974). Combined with the discussion of passive and active decision-making mechanisms, it is conceivable that there is a risk for manufacturing mindset issues. However, as this would venture out in the realm of organizational design, this perspective was merely scraped on the surface.

Other thoughts

On a more general level we could ask whether operational, tactical and strategic decision-making is slowly fusing together. The rationale behind such a general wondering is that; the increasing clock speed of the world combined with the increased openness of systems is diminishing the relevance of freezing the state of reality for investigation of single decisions. At the same time these two phenomena are increasing the complexity of operational decision-making. This would seemingly lead to a situation where the relative importance of the decision-making logic increases, thus elevating concepts such as situation awareness and framing to the core of operational decision-making, which is now dominated by policy.

While a number of further research suggestions can be read in and between the lines of this chapter, most of them emerge from findings which had a small (but pivotal) role in this thesis. While explorative research can be expected to raise more questions than there were to begin with, we should not forget that the single research design of the study implies that some of the findings can be very context specific. The safest approach when evaluating the results of single case studies is to assume that the findings are not generalizable. Considering the chosen methodology, the only way to propose a theory (generalize), is by conducting further case-studies with the same research setup (Eisenhardt 1989). Nevertheless, the developed literature framework should be transportable to basically any context, where revealed deficiencies could improve its applicability also in this context. Further the explicit method of measuring over- and under-service presented here is probably context-, and to some extent also case-specific. However, I do argue that the general principle behind the measure, as it is discussed above, is fully transportable. With these words we shall conclude our discussion, and move to the conclusions, where the contributions and their practical implications are summarized together with thoughts on further research.

9 Conclusions

In this thesis we were able to link installed base information to the value created in preventive maintenance field service operations. Further, we managed to identify a set of challenges in the studied preventive maintenance process, to which solutions were developed in the form of eight design propositions. All of the design propositions featured an improvement in the way installed base information is collected or used. The first of these design propositions called for implementing a learning mechanism to the preventive maintenance resource allocation. This first design proposition was also tested through analyzing its effect through actual service event data, which enabled us to quantify the gap closed through a potential implementation of the first design proposition.

This means that the objective of the thesis was reached through the planned approach, satisfying both the underlying research- and business motives. The research questions, based on the objectives and the approach, were answered in the analysis section. However, the generalizability of the answers suffers from the single case design of the study.

The link between installed base information and value was uncovered through devising a literature framework through which the case was analyzed. By separating active and passive decision-making mechanisms, the analysis uncovered a need for establishing a learning mechanism in the way preventive maintenance resources were allocated. In the discussion (section 8) this finding was tied to servitization as a possible manifestation of the manufacturing mindset, which could lead to an overreliance on passive decision-making mechanisms. More importantly however considering servitization, the literature framework serves as a concrete tool for information flow management and design, which can cause problems for organizations moving from closed system- to open system operations.

A key feature when introducing learning to passive decision-making mechanisms is the utilization of event-data. This was tested when evaluating the effect of implementing the first design proposition, through analyzing event data provided by the case company. The analysis showed that it is likely that the case company currently over-maintains its equipment by at least 5-10%. While the actual implementation of the first design proposition will require concurrent implementation of other design propositions, the developed and tested measures capture the elusive concept of under- and over-maintenance. While this has not been done to date, I argue that it is a result from successfully combining the reliability- and service provision perspectives, adding up to a unique and valuable contribution.

The literature framework is assumed applicable (and useful) also in other contexts. However, this can only be verified through further studies. While the measures are based on existing theory, their final validation requires further studies. This should be done by redoing the analysis on a more substantial population, combined with an explicit statistical reliability analysis. Further the measures should be tested in other similar company contexts, in hopes to find a clear case of under-maintenance which would further improve the validity of the measures. The basic idea behind the measures could also be tested in other contexts with postponed outcomes. The final, but necessary step is to implement an actual learning mechanism, which would validate or overthrow the suggested measures for good.

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Appendix 1 - Call-out rate distribution over time, since last PM visit, all analyzed main components (page 1/6)

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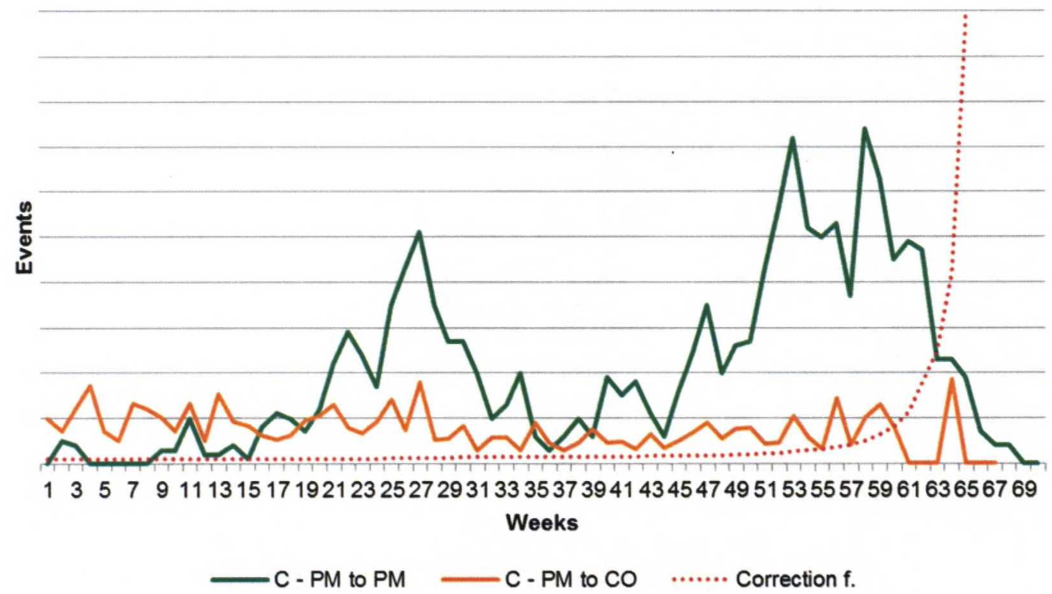
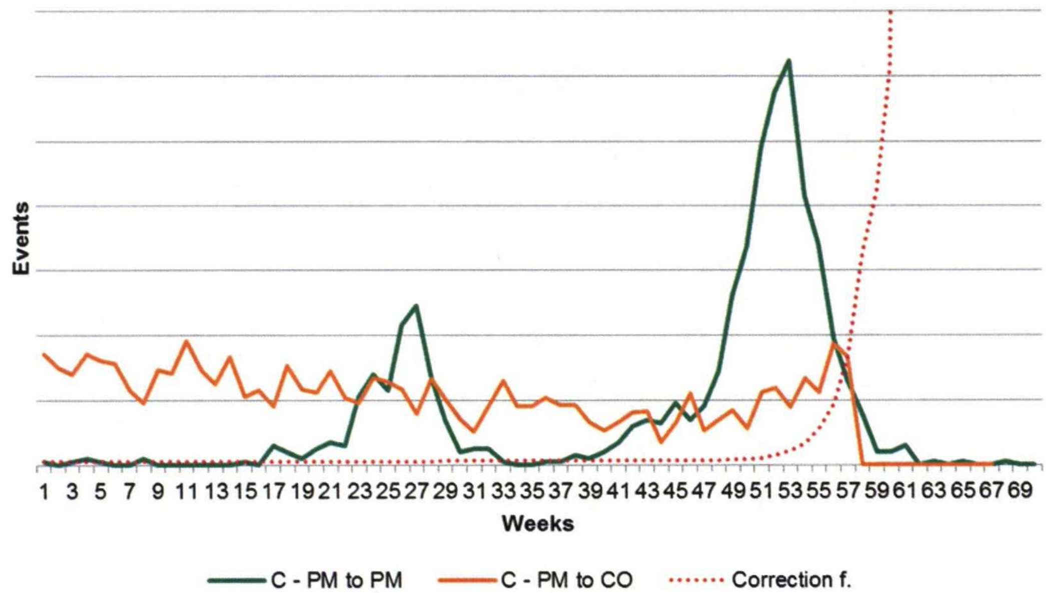
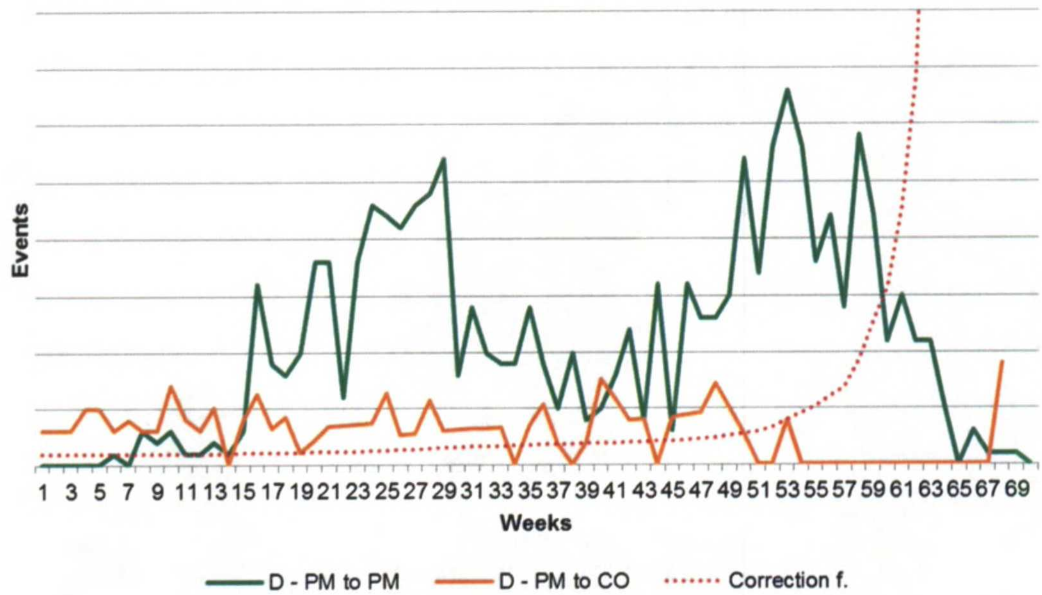
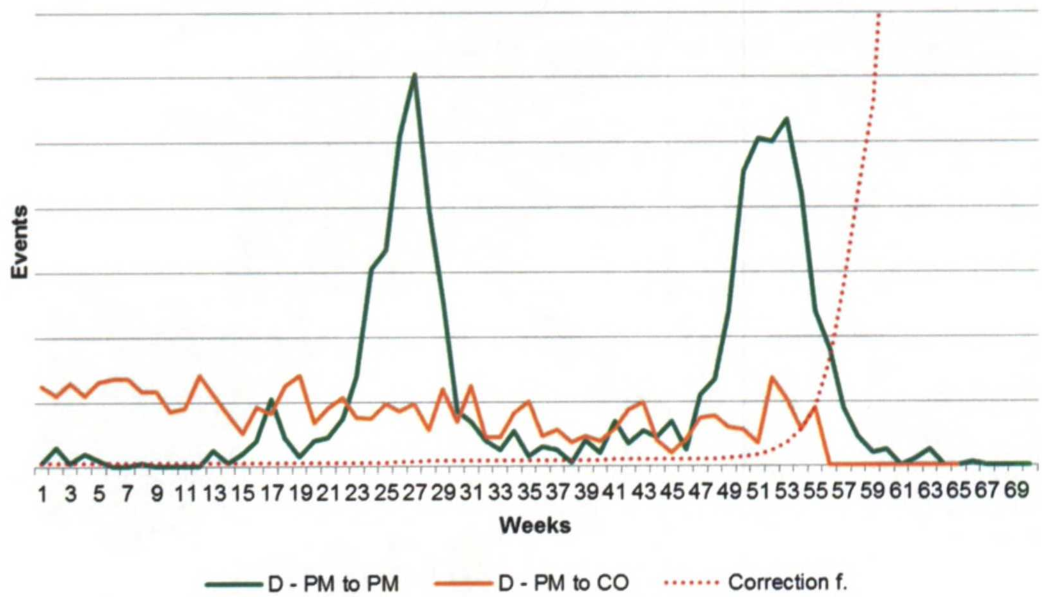


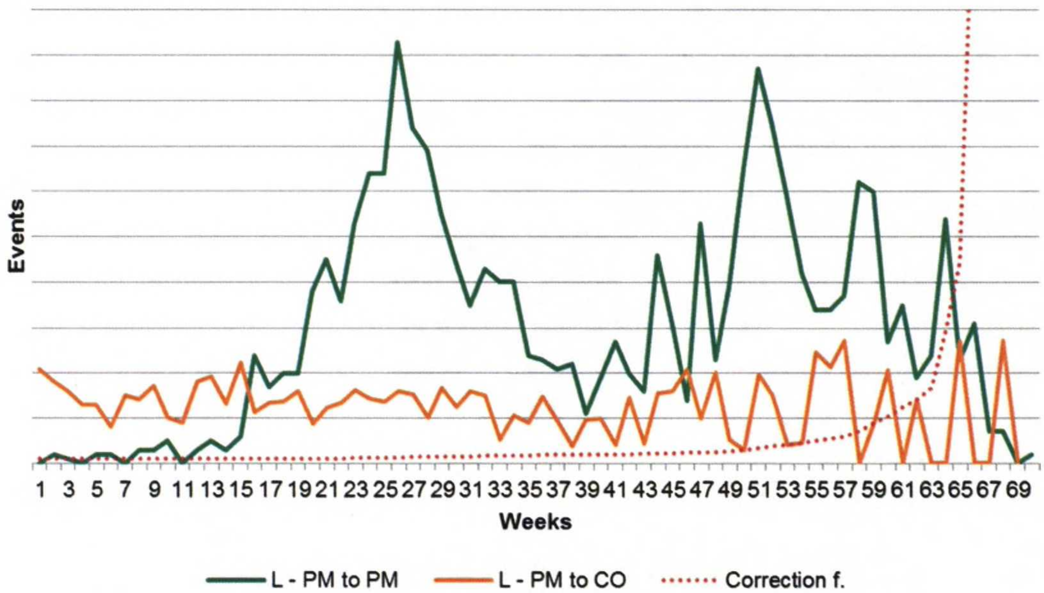


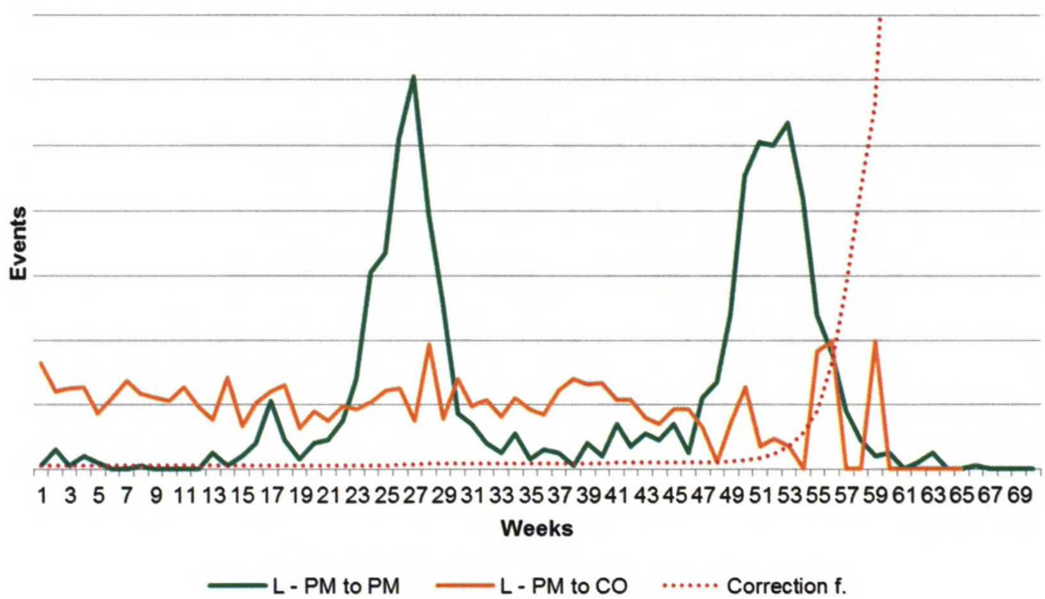
Appendix 1 - Call-out rate distribution over time, since last PM visit, all analyzed main components (page 2/6)





Appendix 1 - Call-out rate distribution over time, since last PM visit, all analyzed main components (page 3/6)





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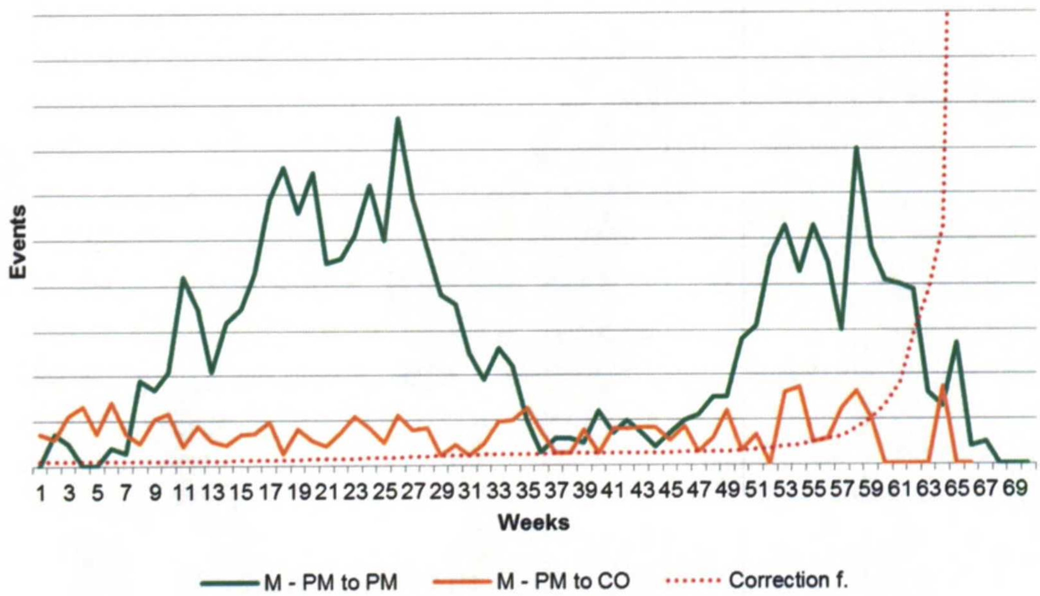

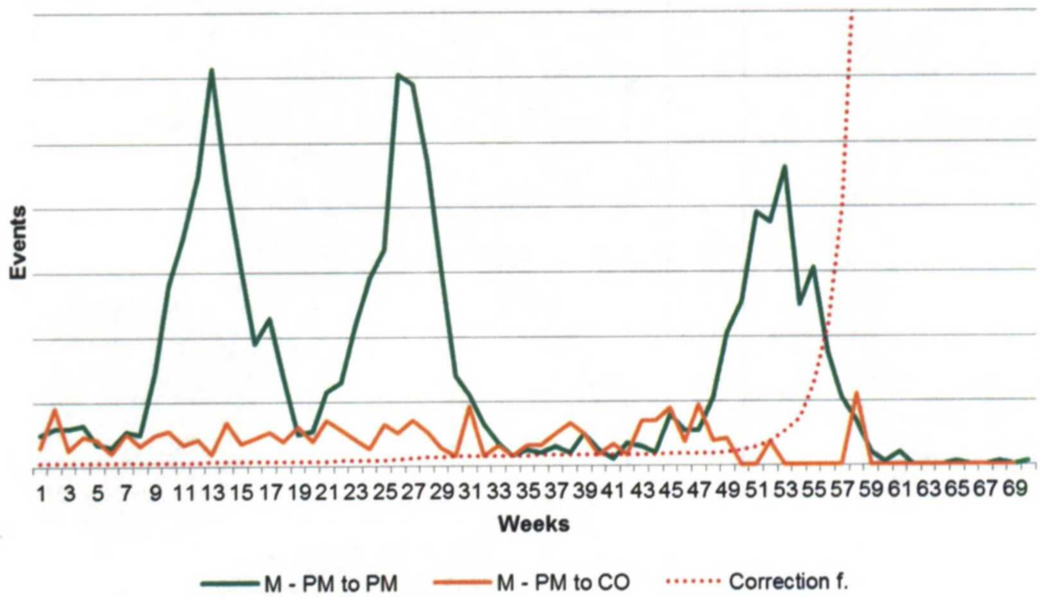

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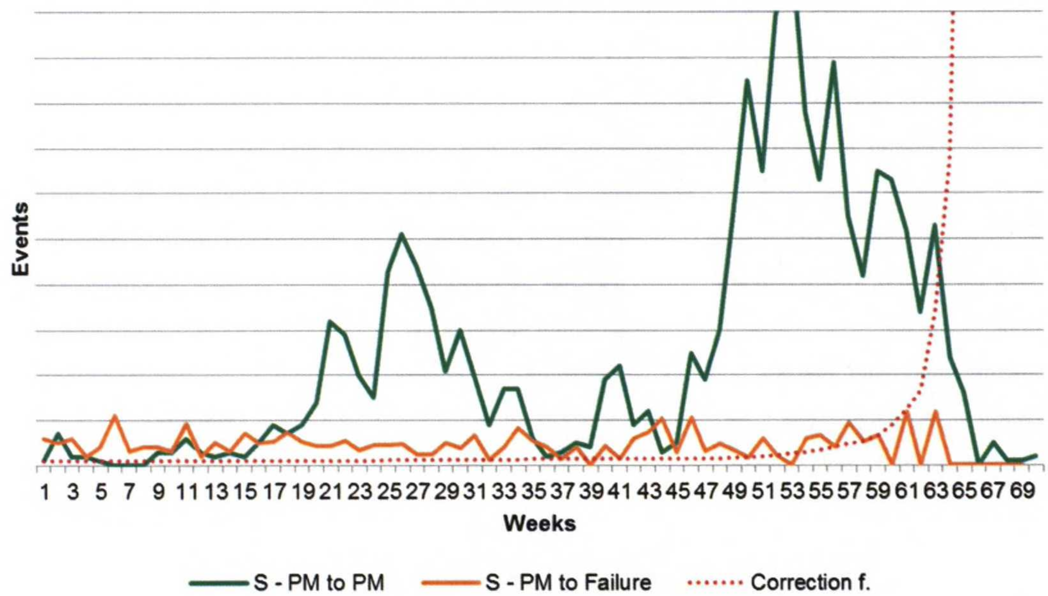
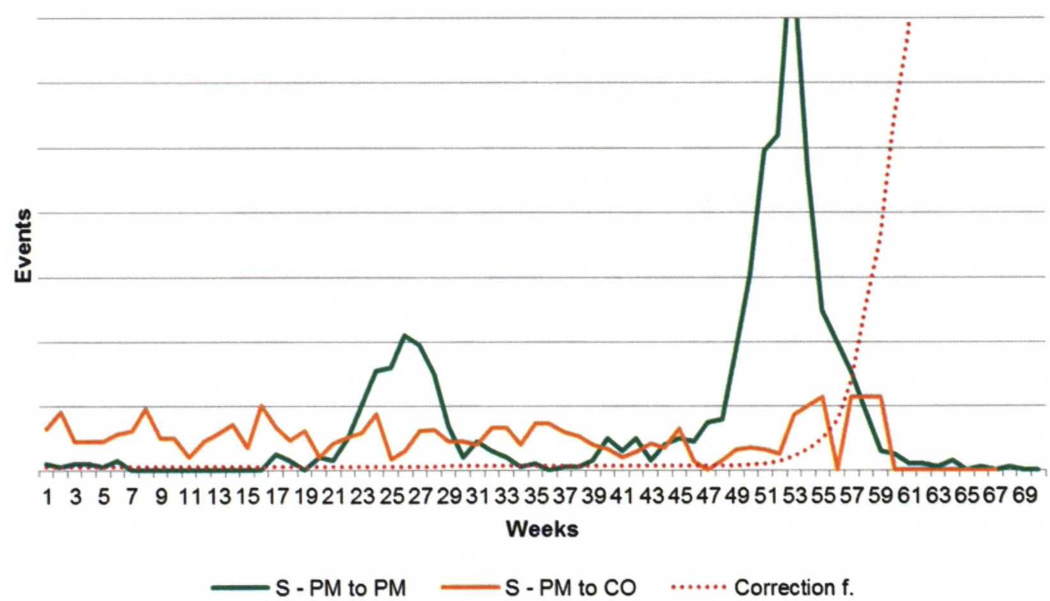
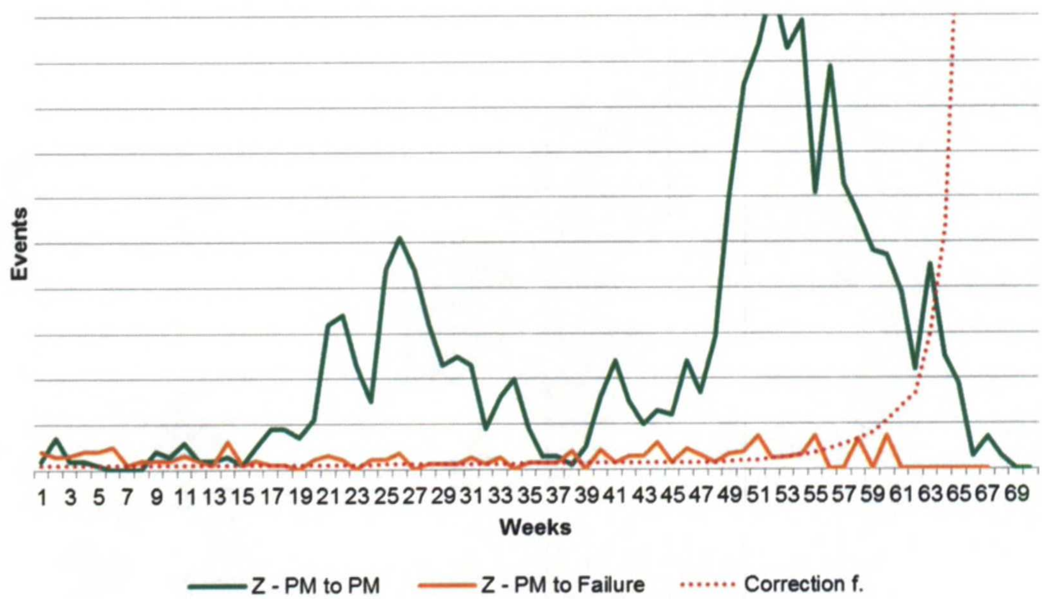
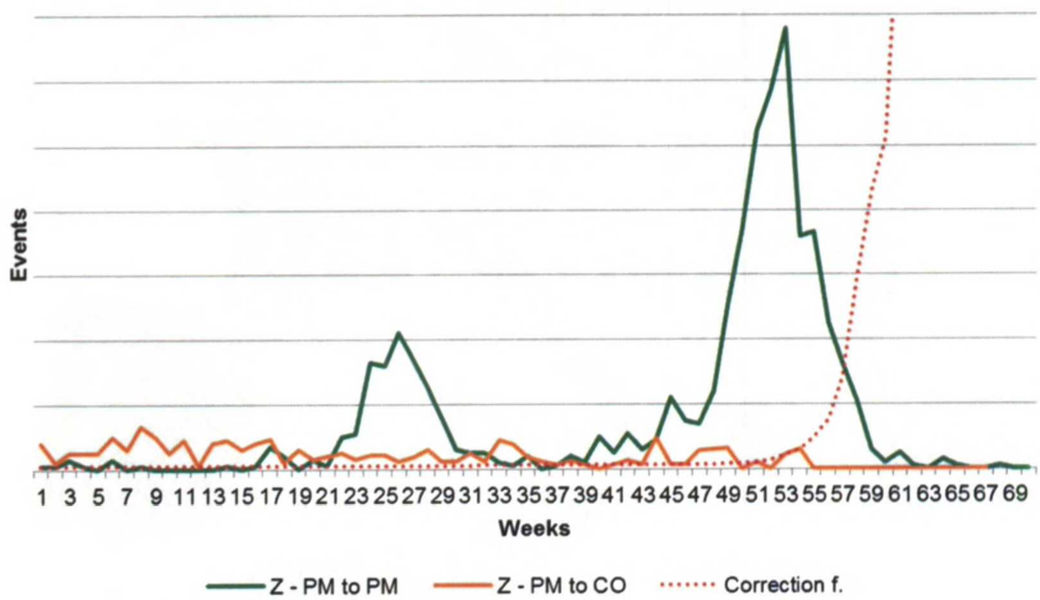


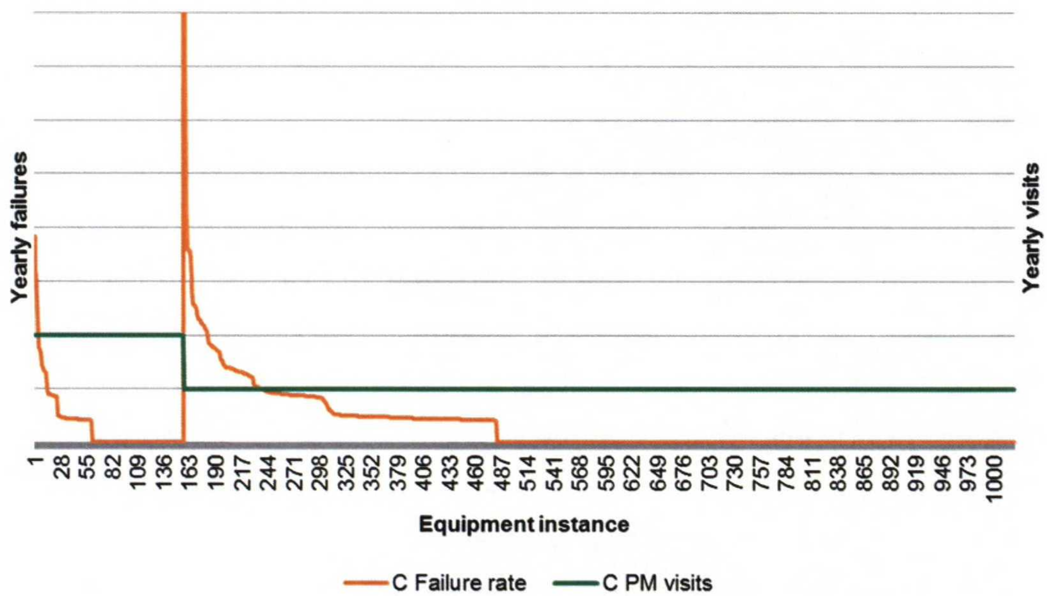


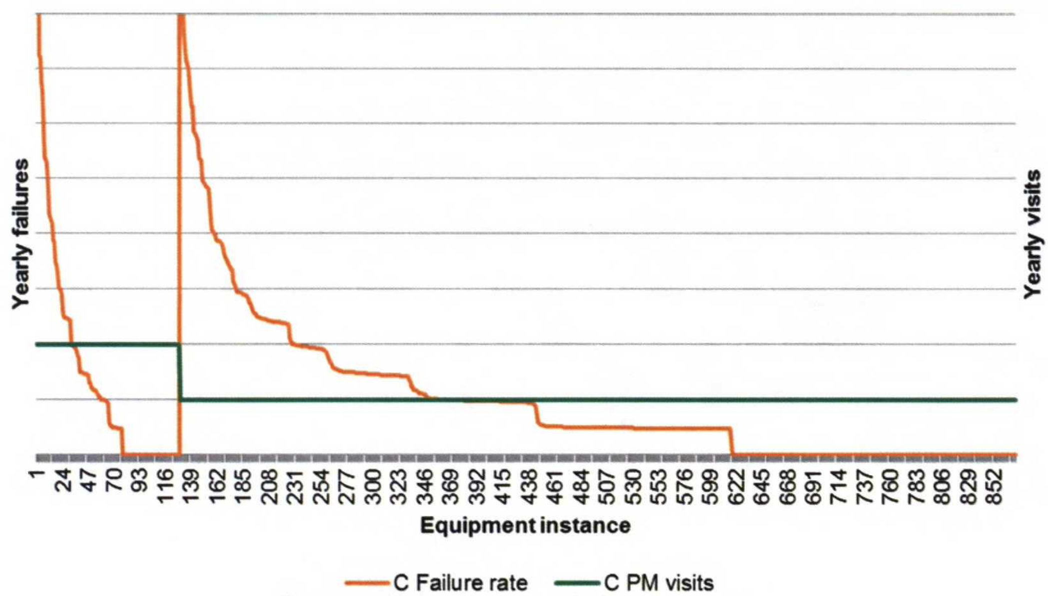
Appendix 1 - Call-out rate distribution over time, since last PM visit, all analyzed main components (page 6/6)



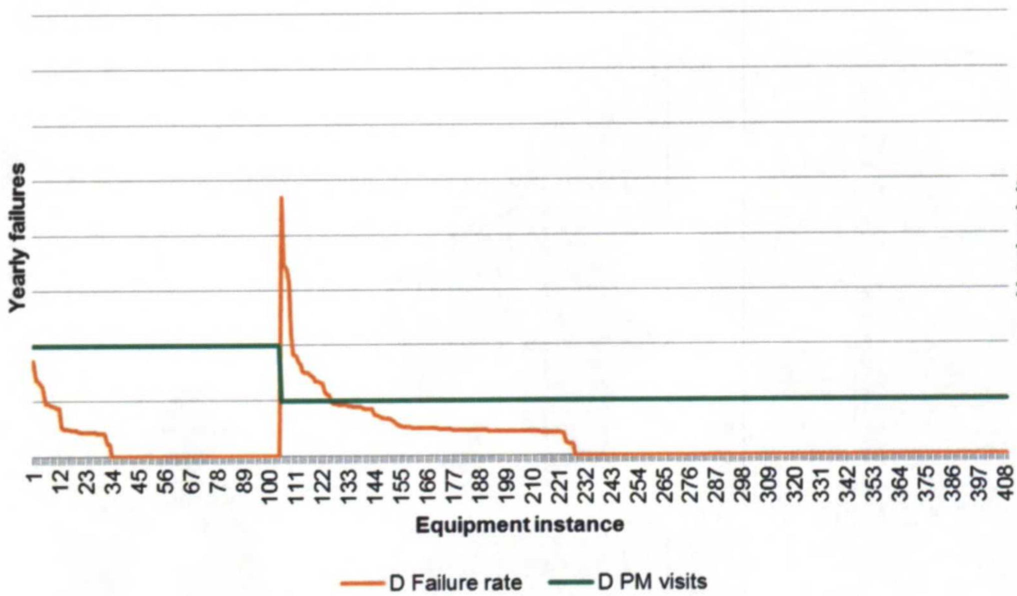


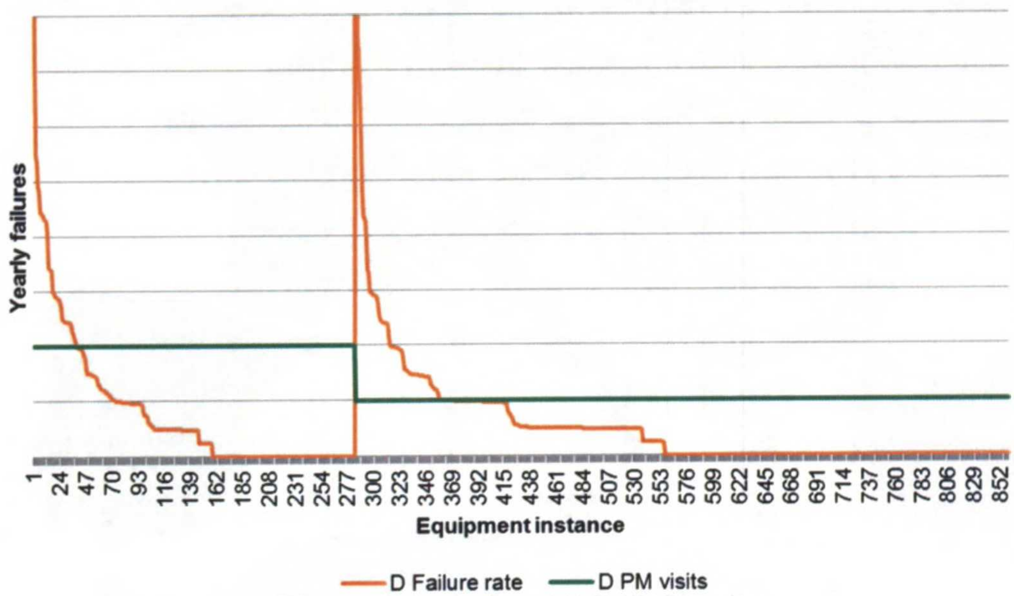
Appendix 2 - Service base failure-rate distribution, all analyzed main components



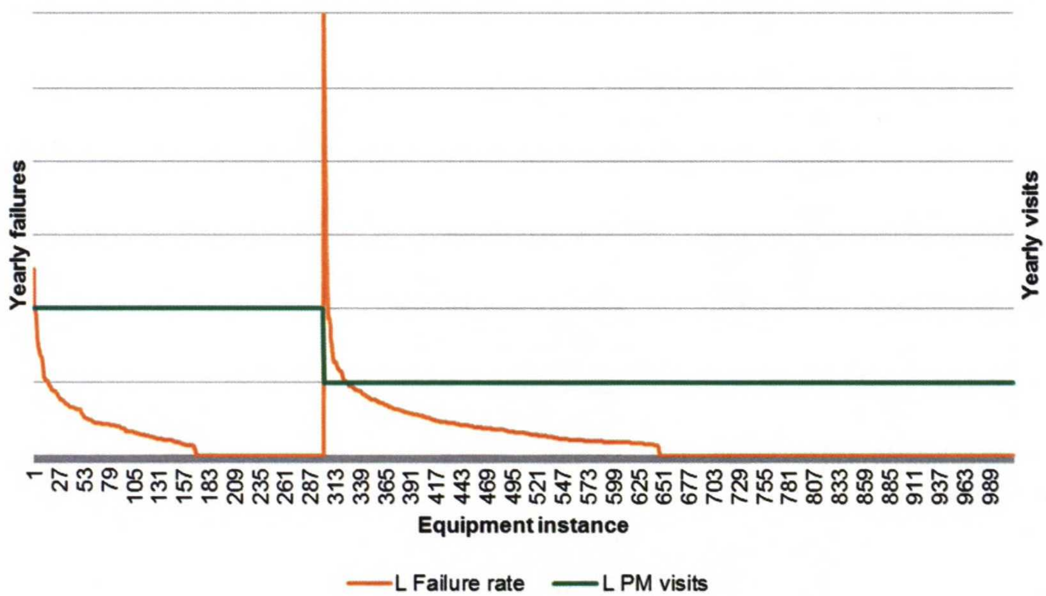


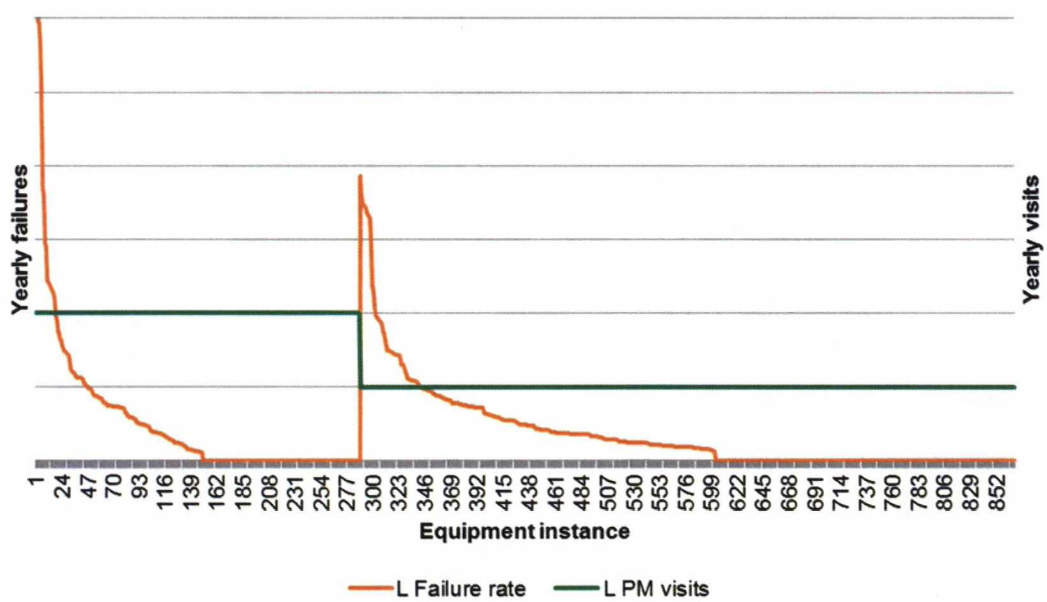
Appendix 2 - Service base failure-rate distribution, all analyzed main components (page 2/6)



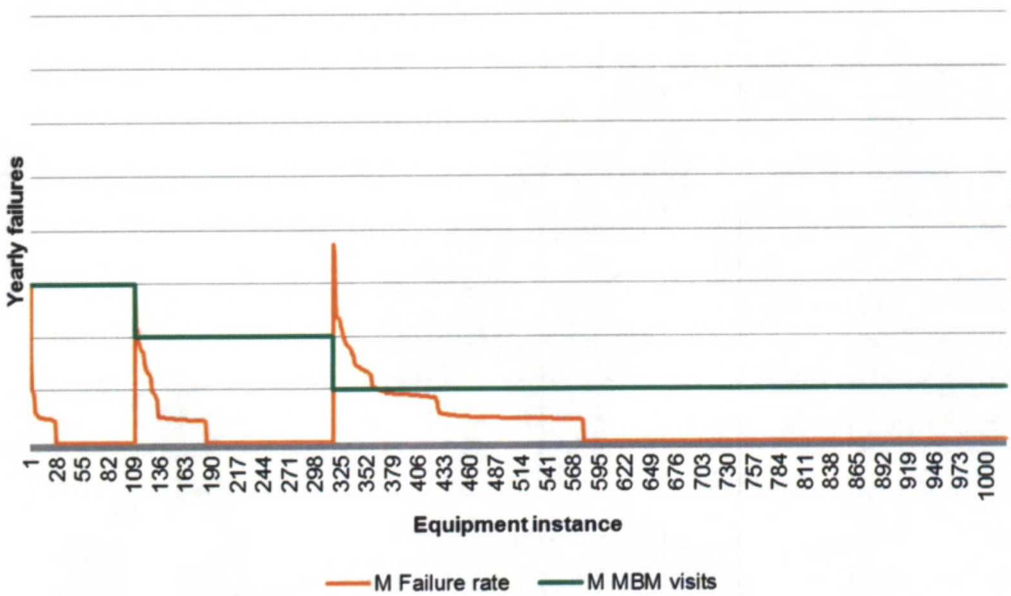


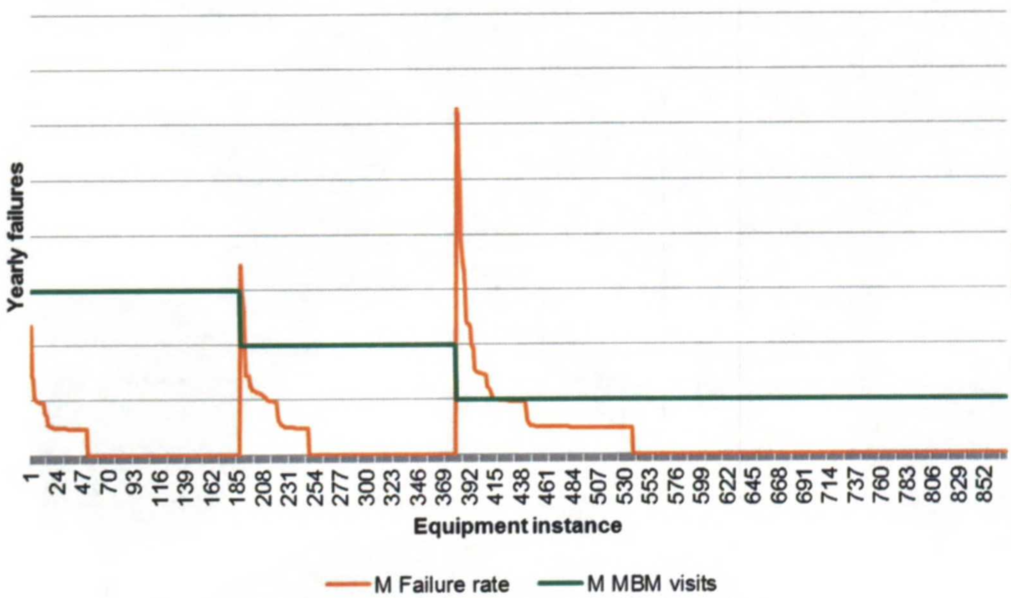
Appendix 2 - Service base failure-rate distribution, all analyzed main components (page 3/6)



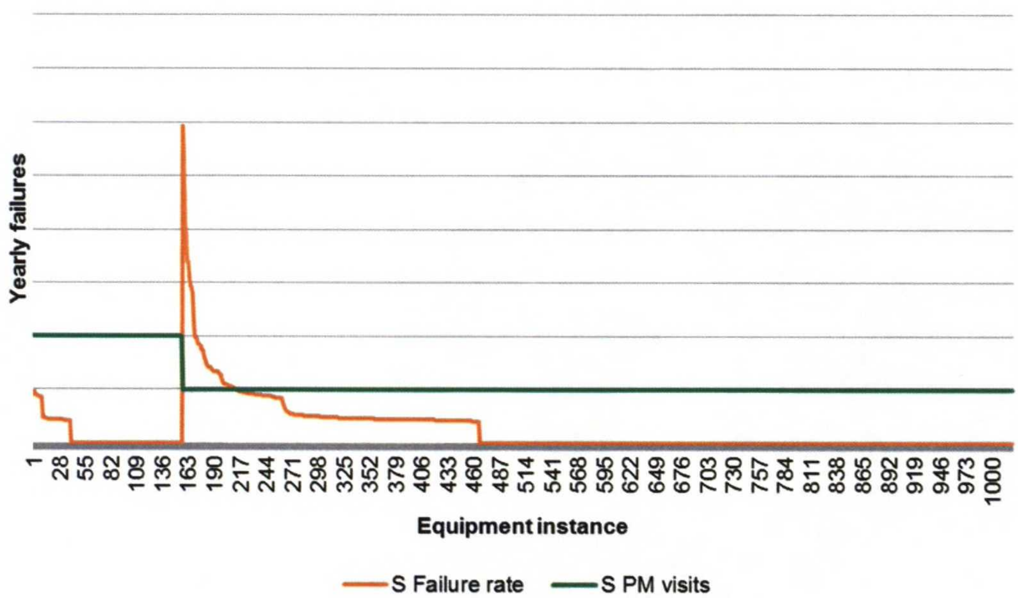


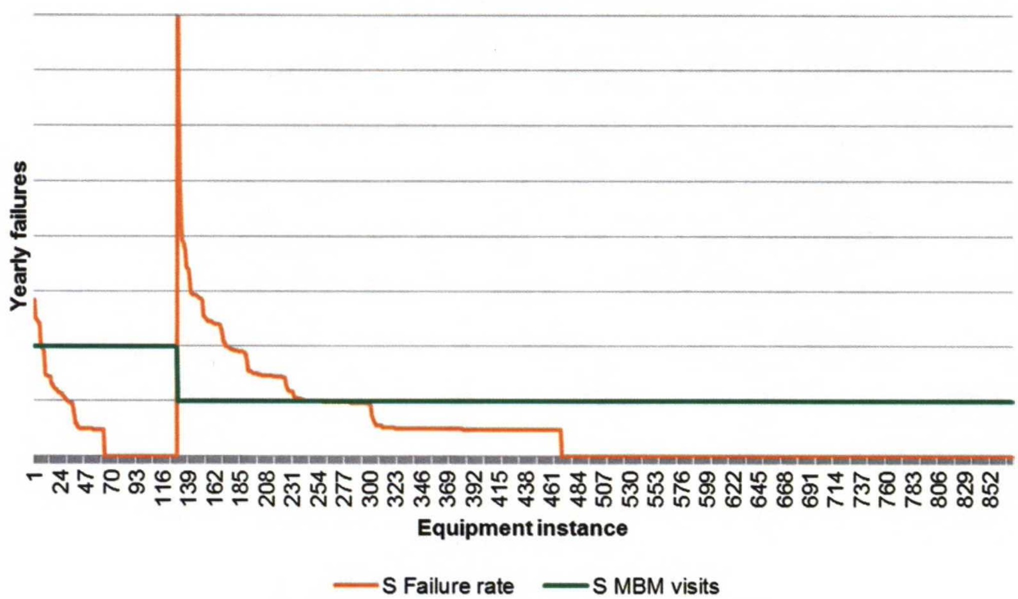
Appendix 2 - Service base failure-rate distribution, all analyzed main components (page 4/6)



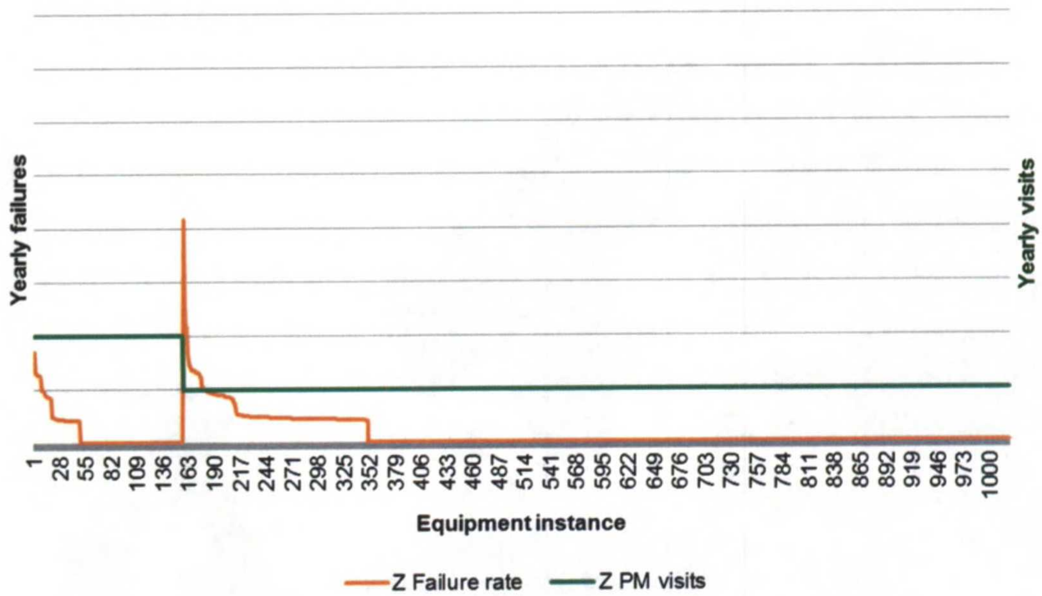


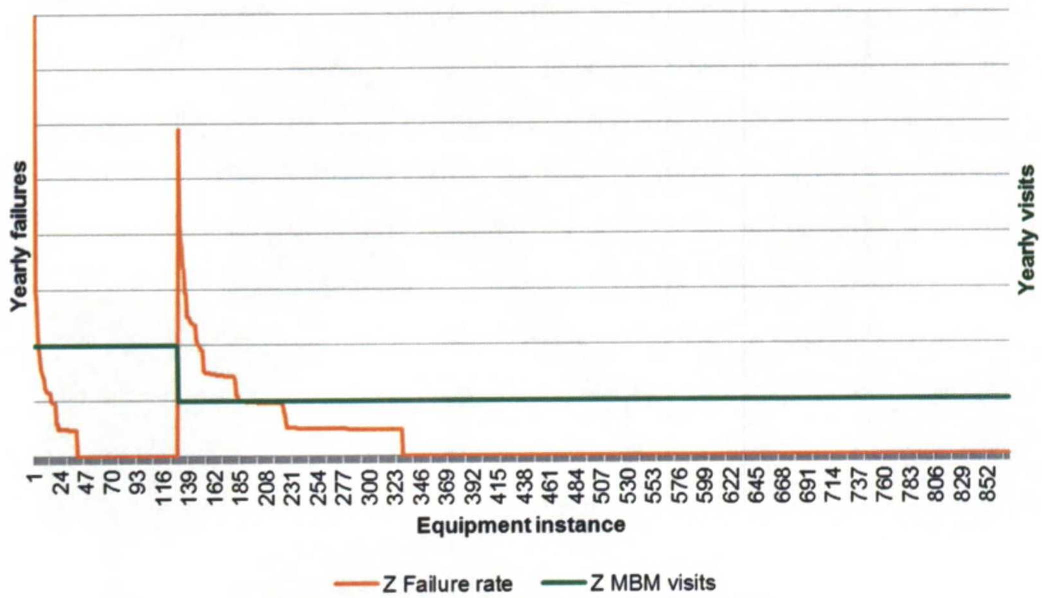
Appendix 2 - Service base failure-rate distribution, all analyzed main components (page 5/6)



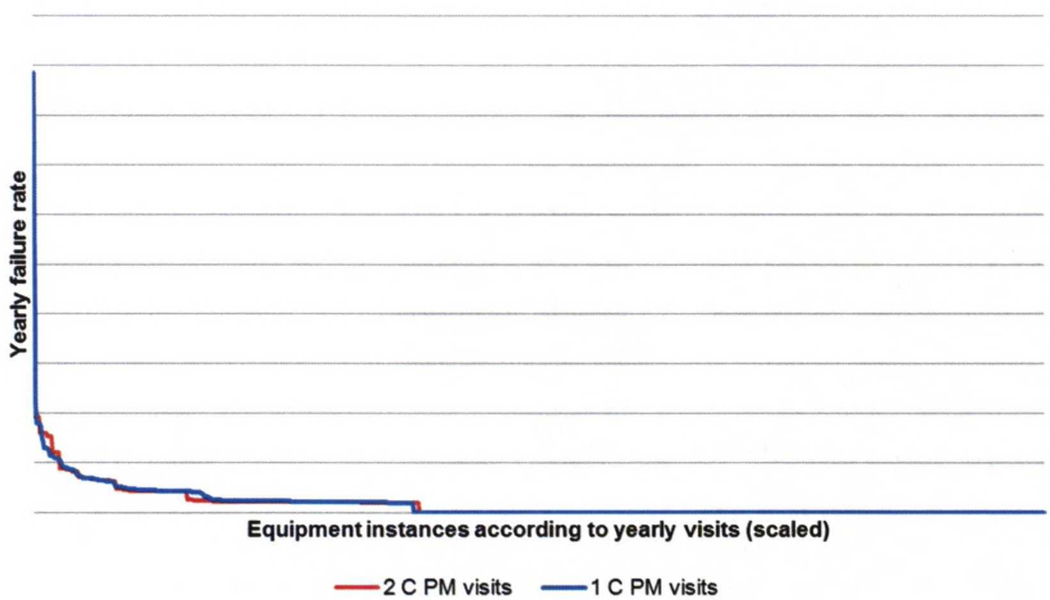


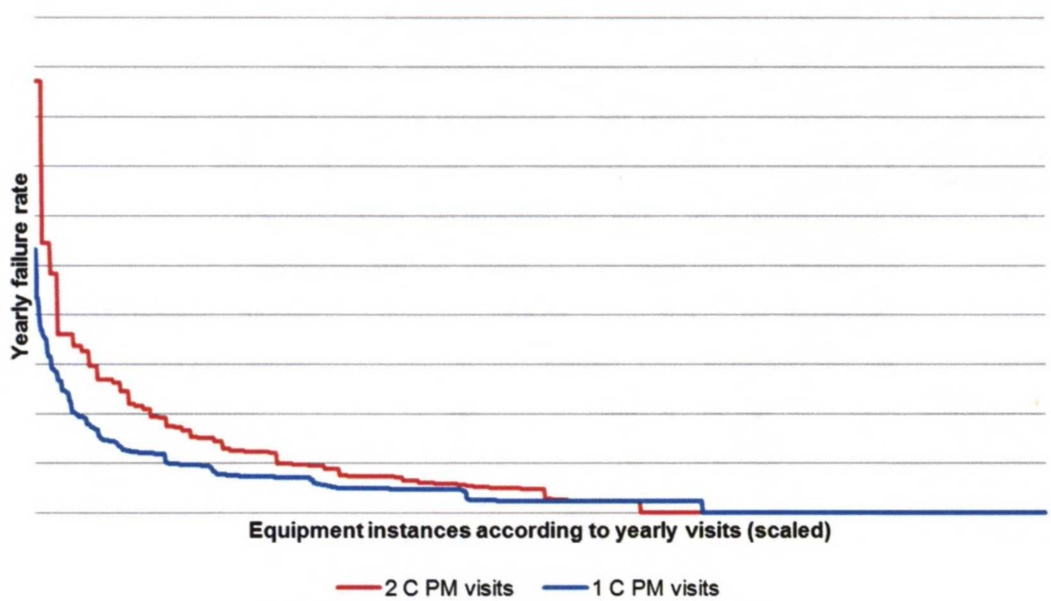
Appendix 2 - Service base failure-rate distribution, all analyzed main components (page 6/6)





Appendix 3 - Preventive maintenance effect on failure-rate distribution, all analyzed main components





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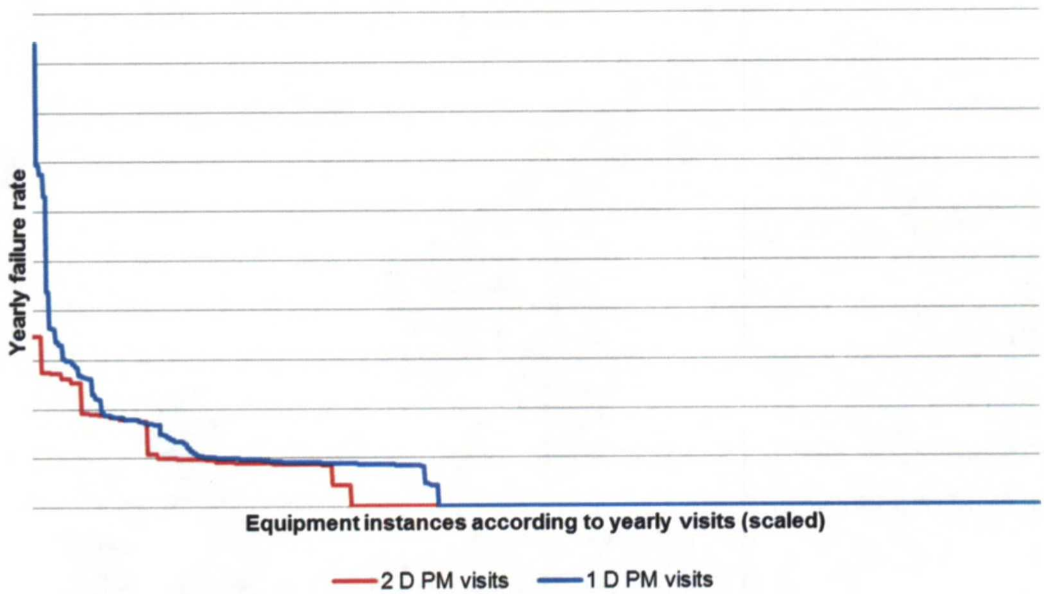

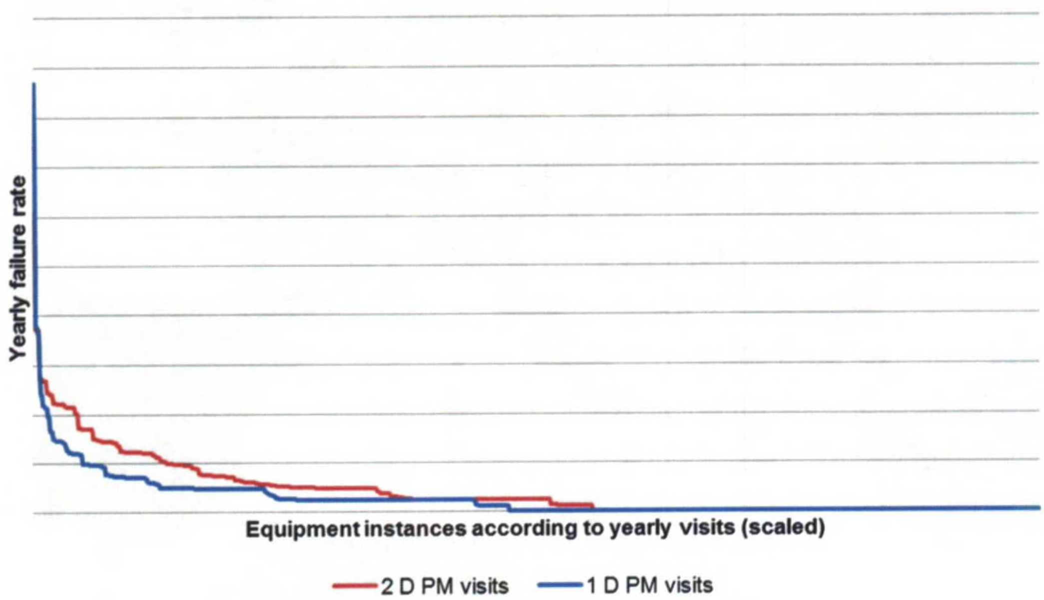

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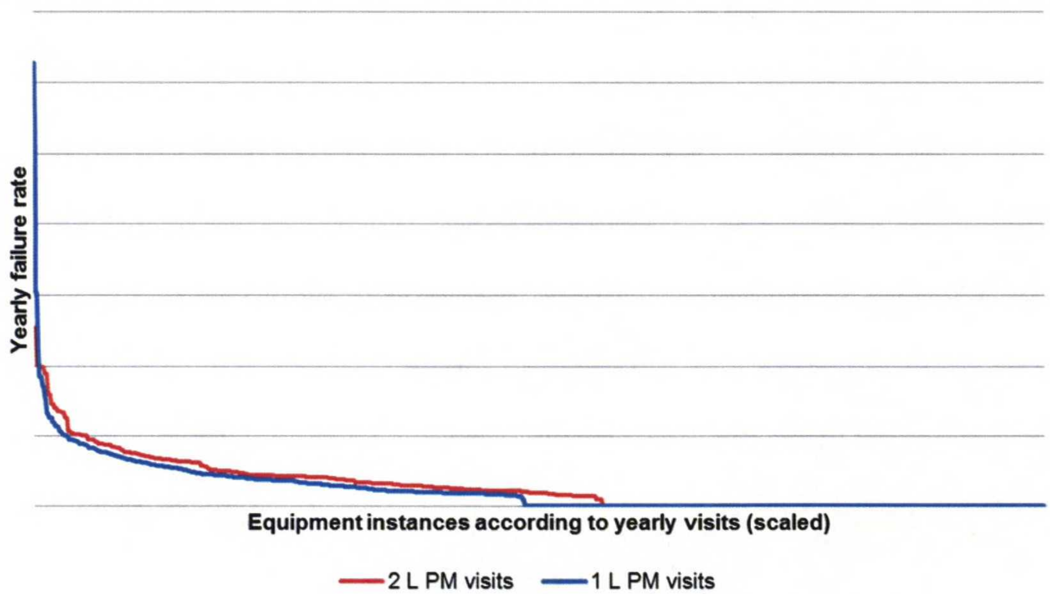

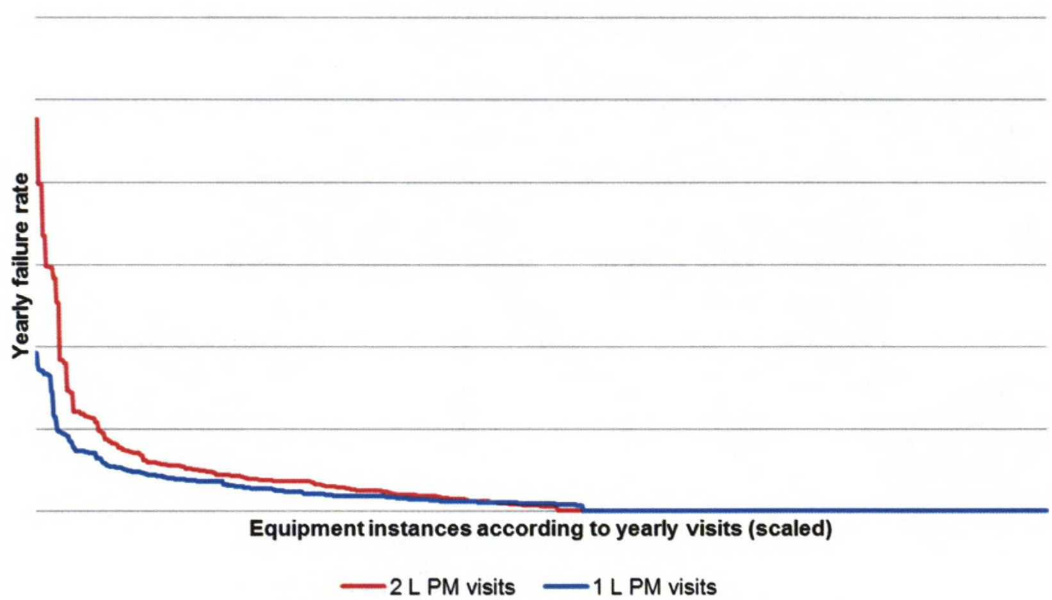

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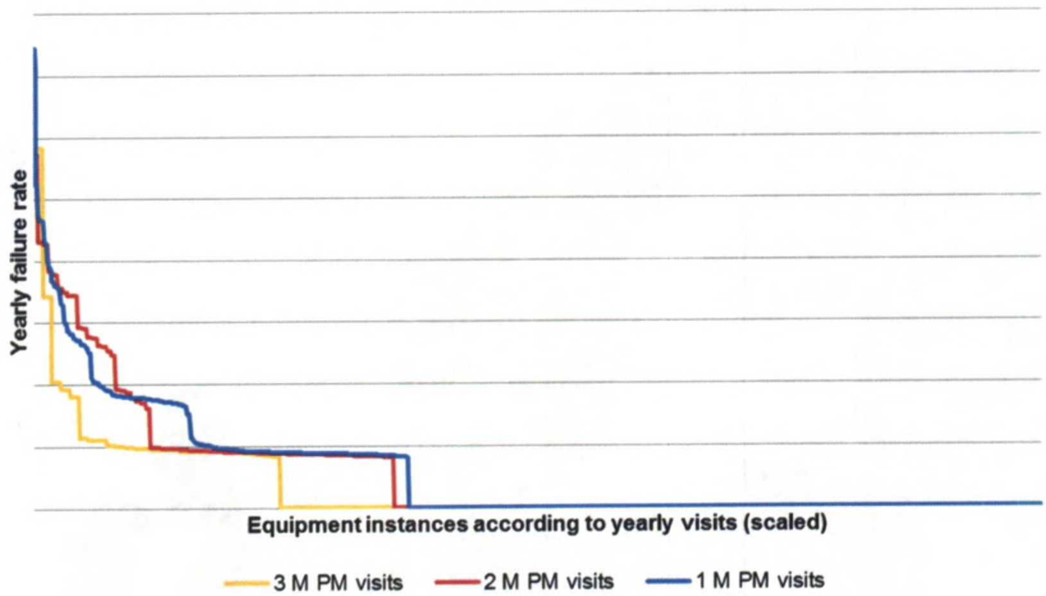

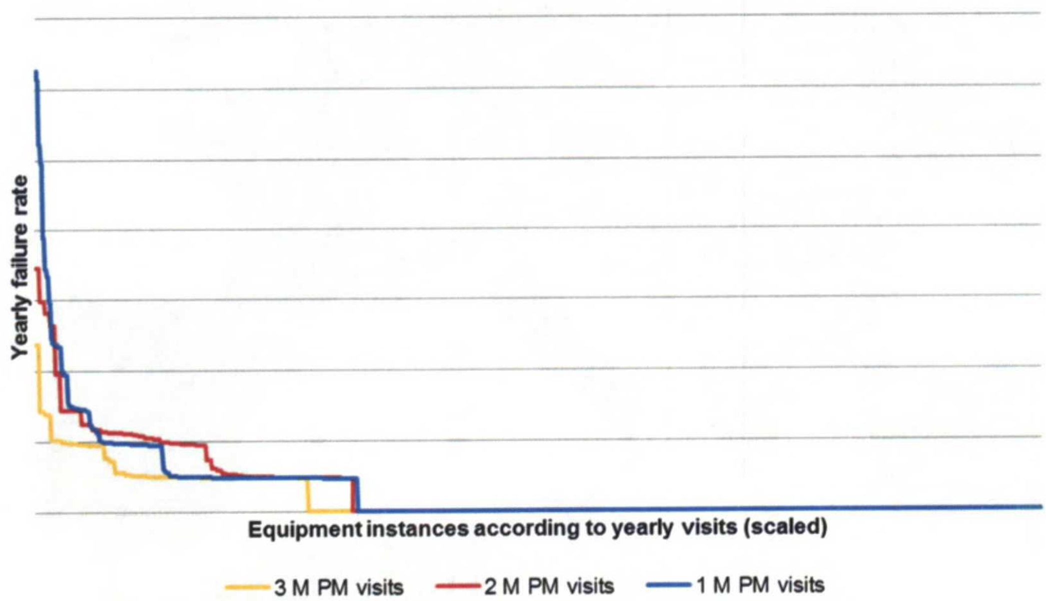

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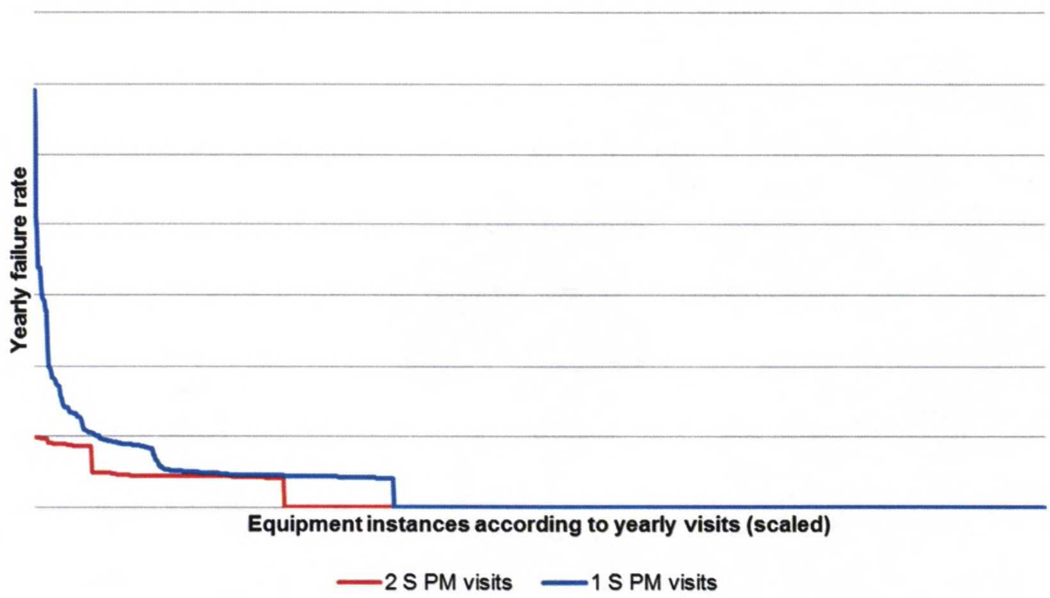

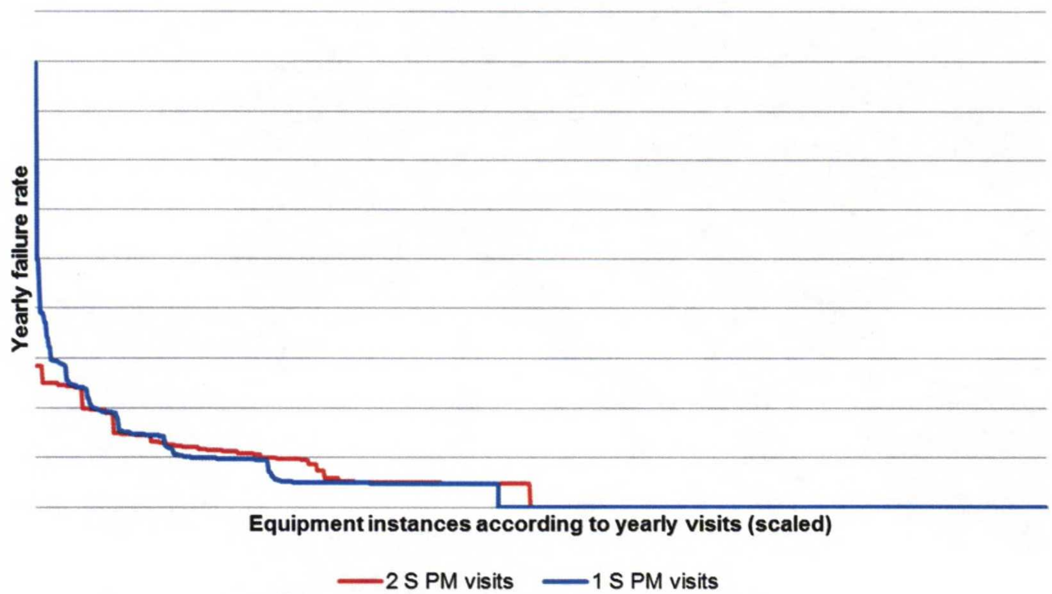

Appendix 3 - Preventive maintenance effect on failure-rate distribution, all analyzed main components (page 6/6)